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CONTENTS

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SEPTEMBER, 1942

WELL SPACING AND PRODUCTION INTERFERENCE IN WEST COLUMBIA FIELD, BRAZORIA COUNTY, TEXAS[1]

JOHN C. MILLER[2]
Houston, Texas

ABSTRACT

The fairly accurate gauges of oil and water production from a great number of wells in the West Columbia field over a period of 20 years, coupled with experiment of movement of fluids in the reservoir, has made possible a comprehensive study of well interference and drainage from the producing sands of this area. The results show that drainage updip, laterally, and downdip can be effected over a distance of 500–800 feet, depending on differential pressures in the reservoir. Information developed indicates that a spacing of one well to 17–20 acres would efficiently drain the sands of this reservoir.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the advice of the several geologists and engineers who aided in the criticism of this paper: R. F. Baker and F. C. Sealey discussed geological developments and W. V. Vietti discussed petroleum-engineering developments. The writer is particularly indebted to Ionel I. Gardescu for his suggestions and constructive criticism, as well as his assistance in preparation of the article.

INTRODUCTION

The West Columbia field is one of the few prolific older fields that has available detailed individual well-production and other well data which permit a rather comprehensive study of well spacing in terms of ultimate recovery and well interference. Since its early development in 1917, this field has experienced the full evolution of production practices.

Inasmuch as the location, geology, physiography, and early history of this dome have been treated in papers by Barton,[3] Carlton,[4] and others, only brief mention is made of these matters in the present article.

[1] Manuscript received, October 27, 1941.

[2] Division geologist, The Texas Company.

[3] D. C. Barton, "The West Columbia Oil Field, Brazoria County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 2 (1921), pp. 212–51.

[4] D. P. Carlton, "West Columbia Salt Dome and Oil Field, Brazoria County, Texas," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), pp. 451–69.

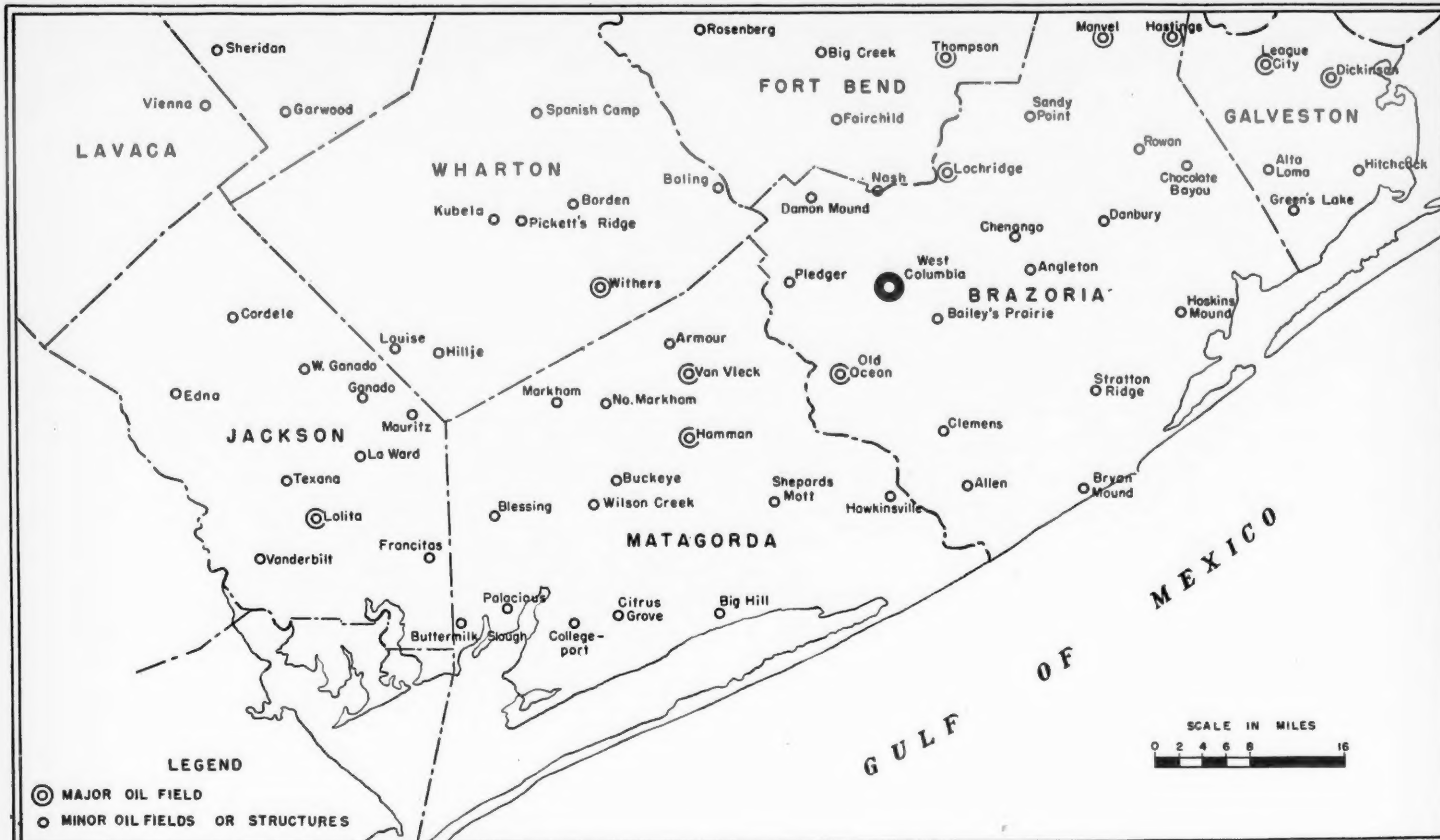


FIG. 1.—Sketch map showing relative location of West Columbia and other domes of Texas Gulf Coast.

LOCATION

West Columbia dome is located northwest of the small town of West Columbia and is approximately 60 miles southwest of Houston, Texas. It lies within the Houston Salt Dome basin, being surrounded by many other piercement and deep-seated domes, as shown in Figure 1.

SURFACE GEOLOGY, PHYSIOGRAPHY, AND HISTORY

The field is near the landward margin of the Beaumont Plain and is expressed in surface beds by an inlier of Lissie sands. The presence of a ridge with an elevation of 5–10 feet above the general plain and a central depression overlying the dome, together with near-by occurrences of gas seeps, highly mineralized waters, paraffine dirt, and oil and gas showings in shallow wells, led to immediate prospecting, following the discovery of oil at Spindle Top, Texas, in 1901.

Early exploration of the dome resulted only in a few small shallow wells in super-cap sands. The first deep (2,900-foot) production, which led to development of the southeastern flank, began in 1917, following the completion of Tyndall Wyoming's well No. 1, located on the western end of what was later known as the Humble Oil and Refining Company's Japhet lease. The production was extended farther south by The Texas Company's Arnold No. 2, completed in 1919, with initial production of 6,500 barrels per day. In 1920, The Texas Company's Abram No. 1 proved the Miocene flank production north of the dome. This well produced, during the first 40 days after completion, approximately one million barrels of oil.

The main production of the West Columbia field, prior to 1937, came from the basal Miocene sands. A few wells, located on the southern flank of the dome in the vicinity of the Japhet fault, produced some oil from the *Heterostegina* and *Marginulina* sands of Oligocene age. Approximately 1,800 feet east of this Oligocene production, several small wells were completed in the Vicksburg sand series during 1936. In 1937, The Texas Company and Sterling Oil and Refining Company completed the first commercial Oligocene producer on the north flank, Phillips No. 1, 2,600 feet north of the Miocene discovery well, Abrams No. 1. The completion of Phillips No. 1 led to the recent development of the *Marginulina* and Frio sands on the northern flank of the dome.

The West Columbia field has produced 80,573,000 barrels of oil to January 1, 1941. Most of this production came from the basal Miocene sands.

SUBSURFACE GEOLOGY

The structural features of the West Columbia dome are shown in Figure 2. The contouring has been drawn on top of the basal Miocene sands. The flanks of the dome are intensely faulted and the structural position of the resulting segments bears an important part in their relative productivity.

On the northwest flank of the dome, a complex faulted area separates the Williams Subdivision segment from the prolific northern segment. The Williams

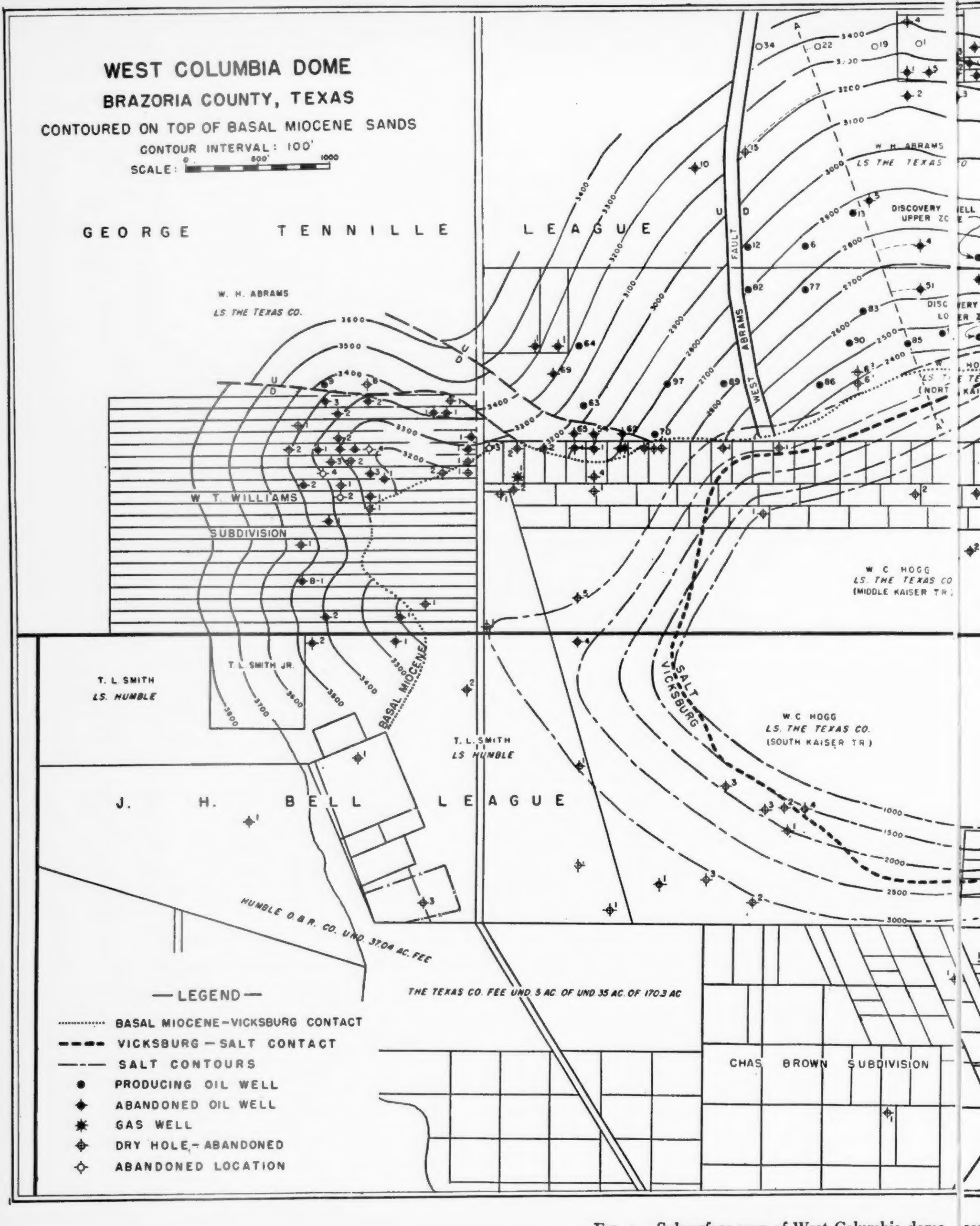
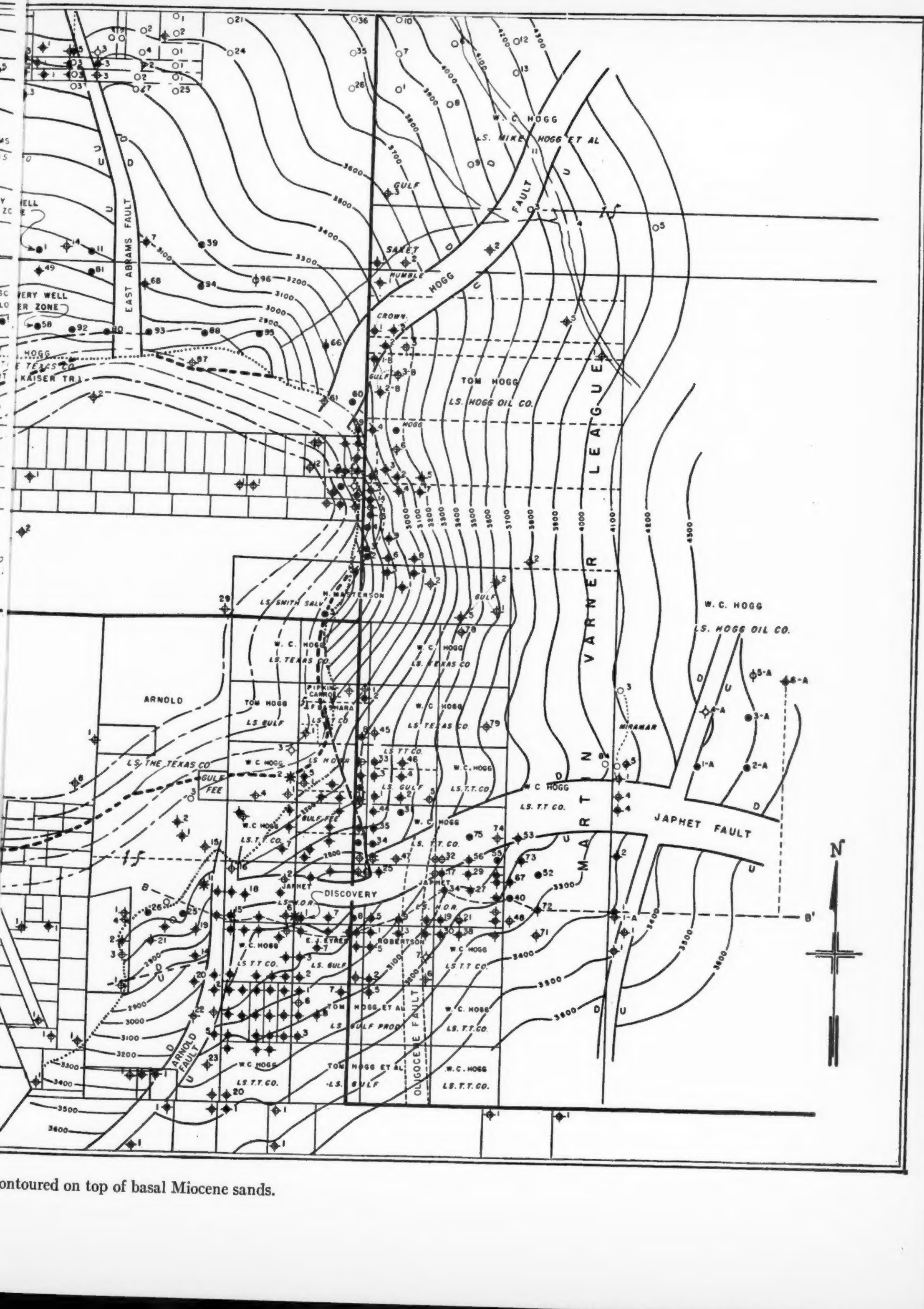


FIG. 2.—Subsurface map of West Columbia dome, co



ontoured on top of basal Miocene sands.

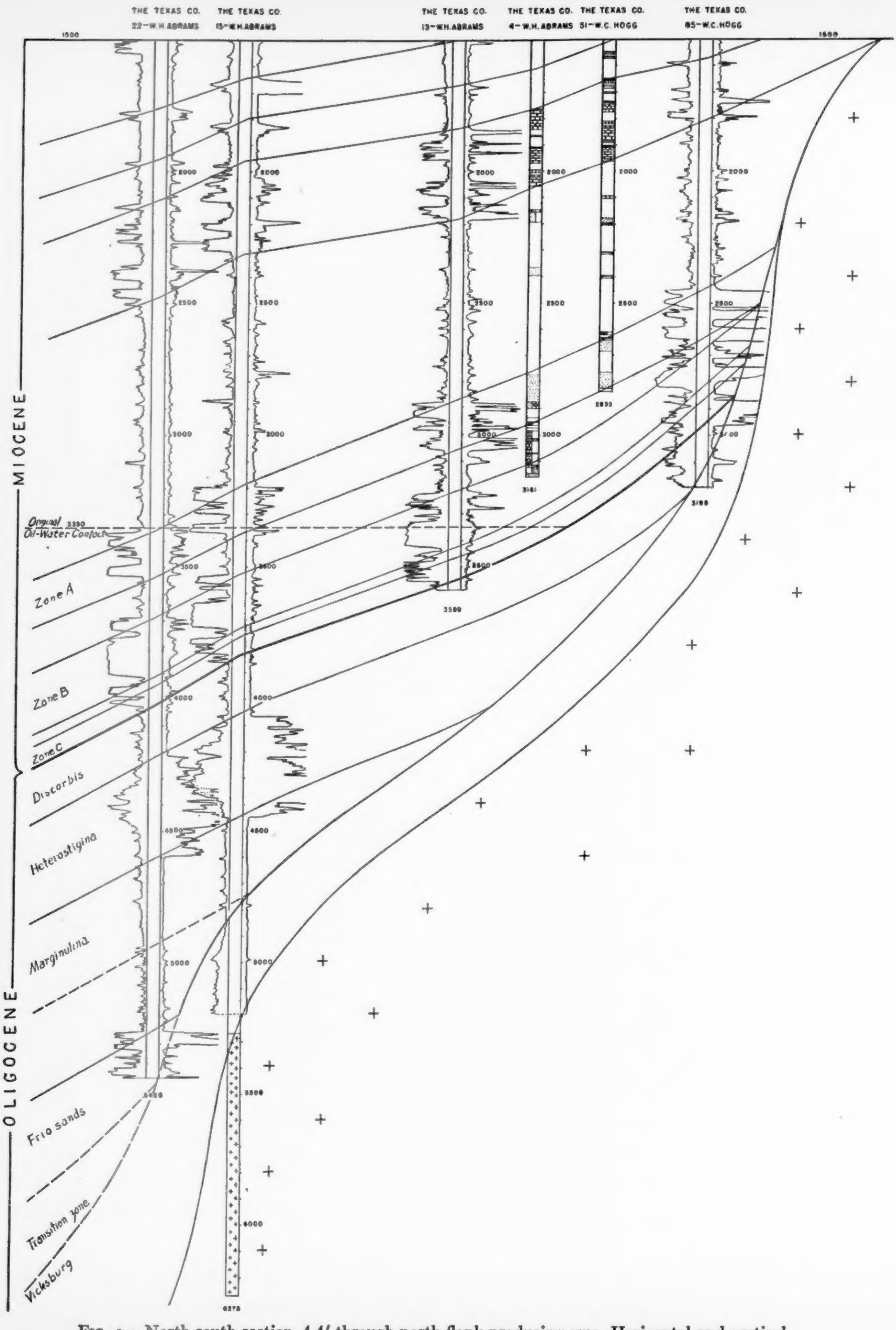


FIG. 3.—North-south section *AA′* through north flank producing area. Horizontal and vertical scale: 0.16 inch = 100 feet.

Subdivision segment had an original water level in the basal Miocene sands that was 150 feet lower than the original water level of the adjacent segment. The production of the Williams Subdivision was relatively small and erratic. The fault zone corresponds with a pronounced nose of heaving shale extending into the eastern part of the subdivision.

The northern segment, extending from the Williams Subdivision fault zone, on the west, to the Hogg fault, on the east of the dome, is subdivided into two producing units by the East Abrams fault. This fault also corresponds with a slight bulging of the salt though not as pronounced as the heaving-shale nose in the first area. In the northern segment, west of the East Abrams fault, the full sand section of the basal Miocene sands is uniform and well developed, as shown by the cross section *AA'* (Fig. 3). The West Abrams fault is of small magnitude and does not seem to have prevented migration of oil as evidenced by similar water levels of recent completions in both areas. The northern segment on the east and on the down thrown side of the East Abrams fault has been less productive because of less favorable structural position. The original water level in the entire northern segment seems to have been the same, occurring at approximately 3,350 feet.

The eastern segment extends from the Hogg fault, on the north, to the Japhet fault, on the southeast of the dome. In this segment, the dip of the beds is steeper and the basal Miocene sand section is not well developed, as a result of which the productivity of the area was relatively small.

The Japhet fault, with a displacement of 700 feet, played an important part in the accumulation of oil in the southeastern segment. A heaving-shale bulge shown on the structural map (Fig. 2), on the southeast side of the dome, ties in with the Japhet fault through a very steep fault of approximately the same vertical displacement as the Japhet fault. The segment is limited on the west by the Arnold fault.

The southeastern segment is divided into two producing units by the presence of an Oligocene fault. This fault shown in cross section *BB'* (Fig. 4), can not be traced into the upper Miocene beds on the basis of the available drillers' logs. Furthermore, the correlation of sands and accumulation of oil leads to the conclusion that the southeastern segment area west of the Oligocene fault was uplifted prior to or during the period of deposition of the lower zone of basal Miocene sands. The lower zone is absent either through erosion or non-deposition on the uplifted block, whereas the upper zone of the basal Miocene sands extends throughout the entire segment.

On the western and downthrown side of the Arnold fault and extending a short distance updip to the contact with a pronounced bulge of heaving shale is a small none-too-prolific segment. Between this segment and the Williams Subdivision segment the wells shown on the South Kaiser Tract and the T. L. Smith leases are old wells, located well up on the dome and drilled a short distance into the Vicksburg heaving shale.

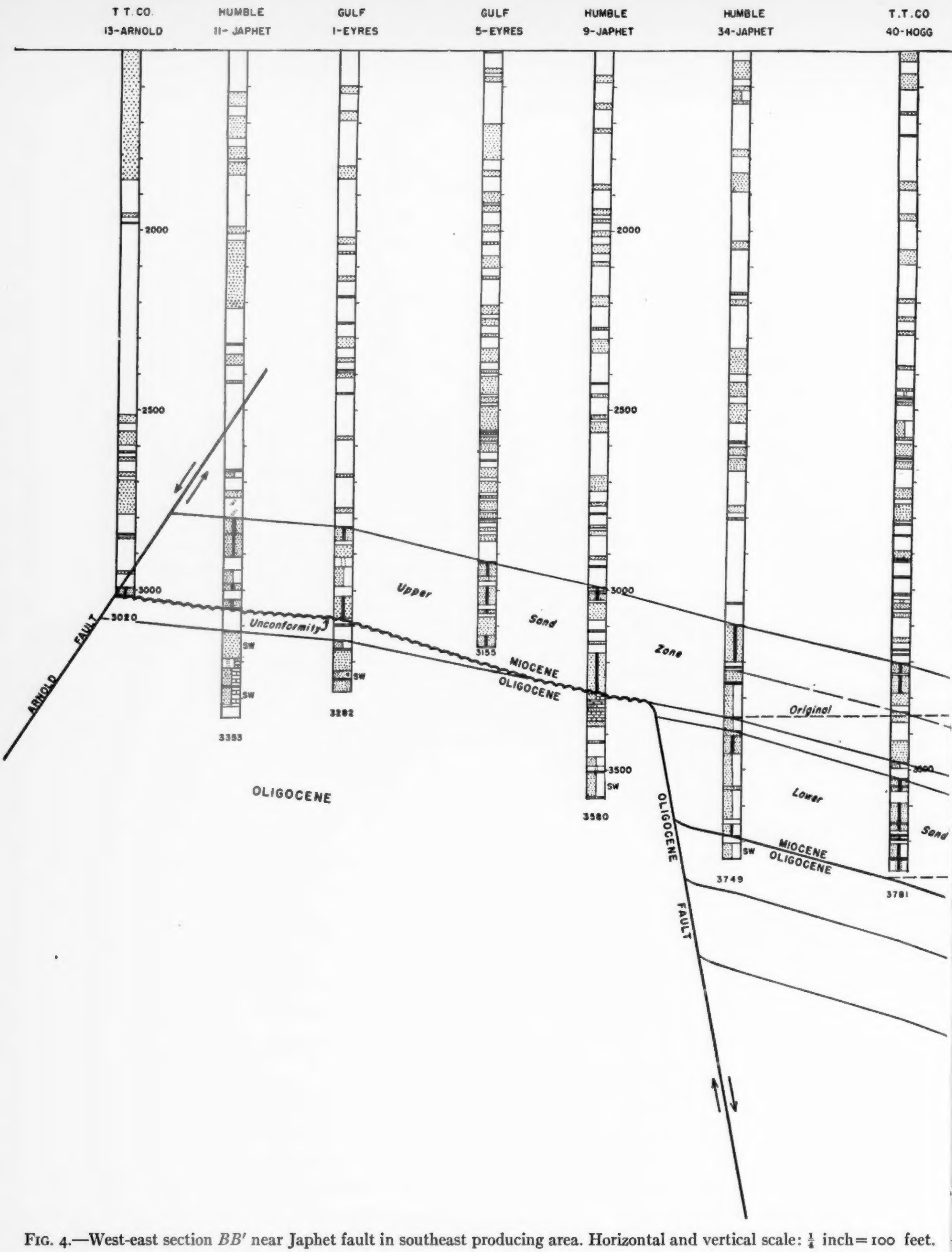
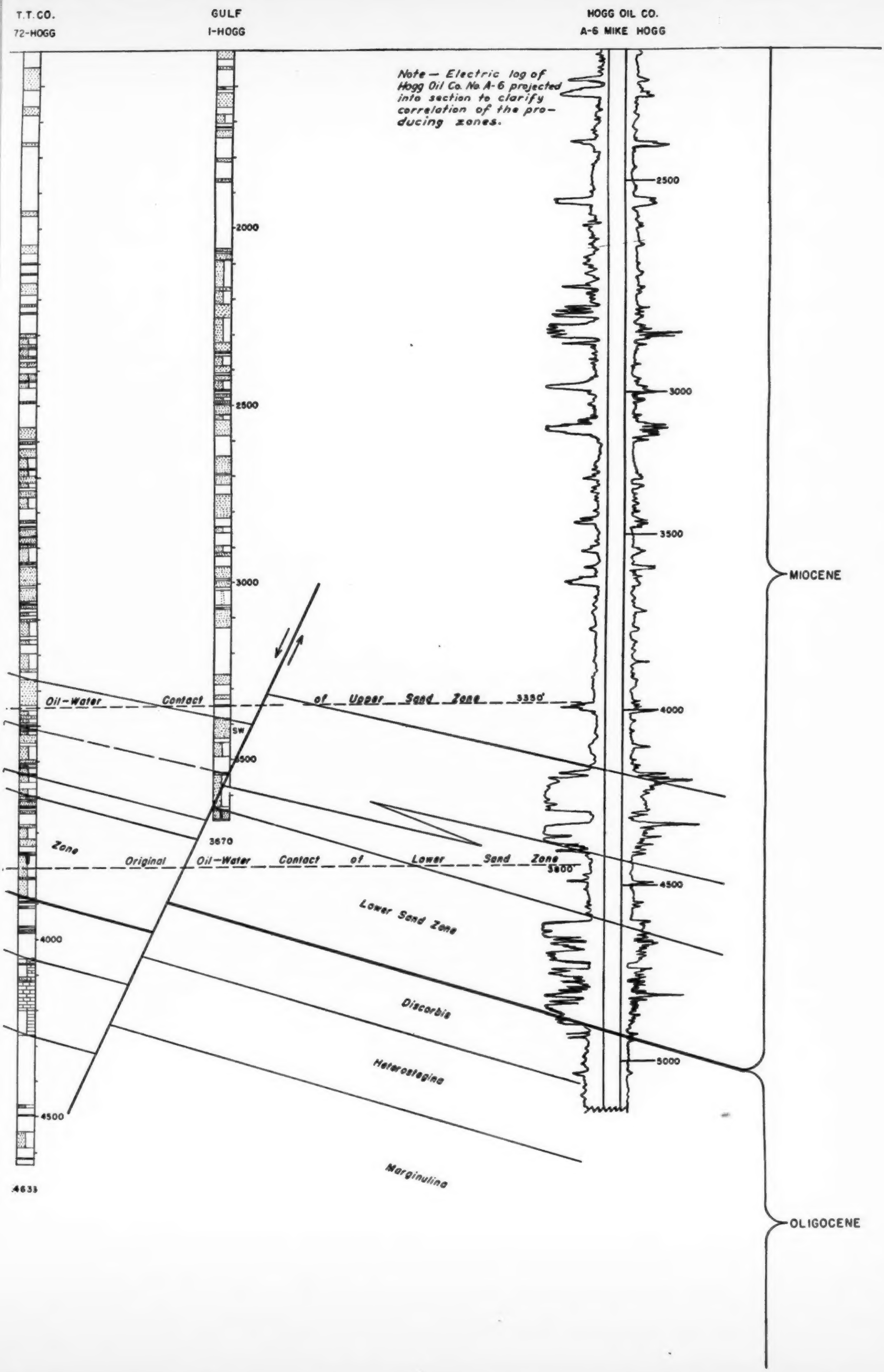


FIG. 4.—West-east section *BB'* near Japhet fault in southeast producing area. Horizontal and vertical scale: $\frac{1}{4}$ inch = 100 feet.



T.T. CO.
72-HOGG
GULF
I-HOGG
HOGG OIL CO.
A-6 MIKE HOGG
Note — Electric log of Hogg Oil Co. No. A-6 projected into section to clarify correlation of the producing zones.
2500
2000
3000
2500
3500
3000
MIOCENE
Oil-Water Contact of Upper Sand Zone 3350'
4000
SW
3500
3670
Zone
Original Oil-Water Contact of Lower Sand Zone 3600'
4500
Lower Sand Zone
4000
Discorbis
Heterostegina
5000
4500
4635
Marginulina
OLIGOCENE

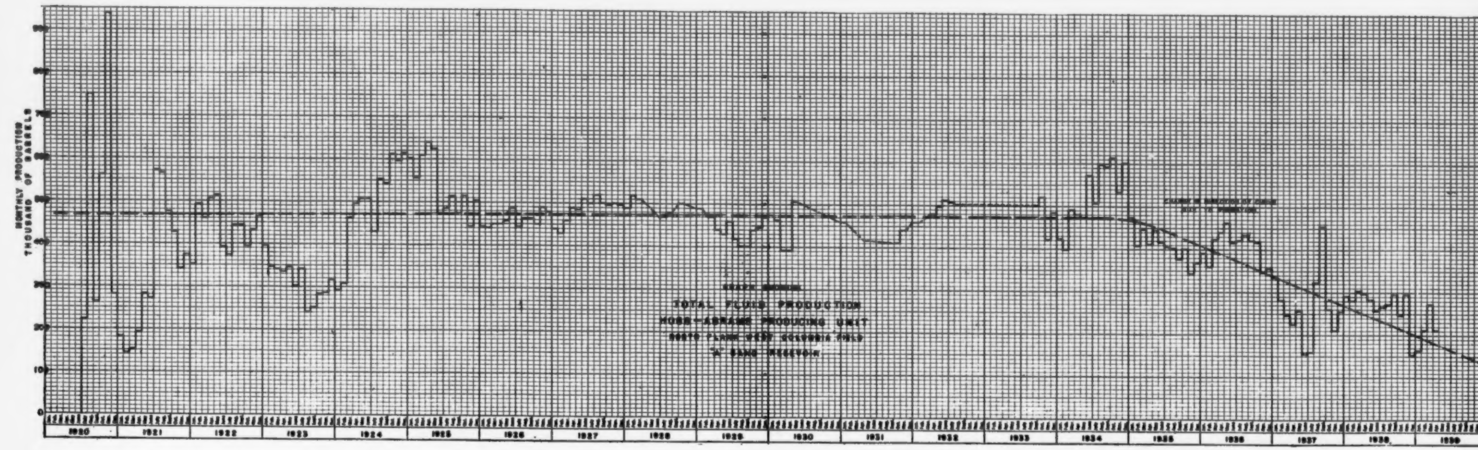
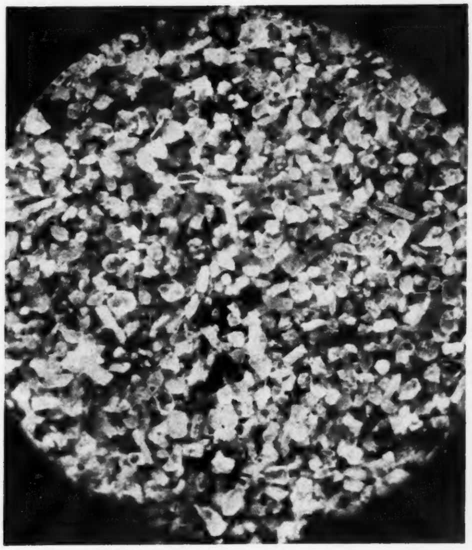
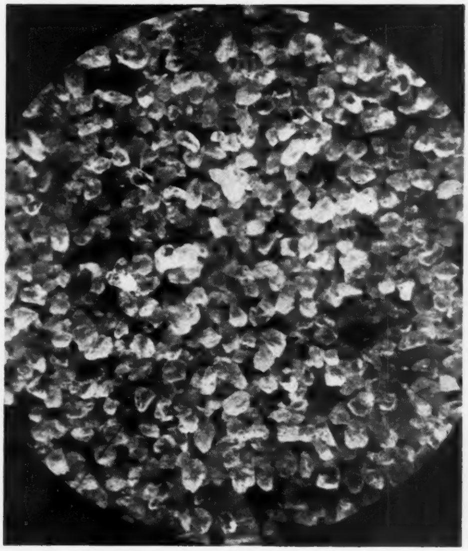


FIG. 6.—Graph showing total fluid production Hogg-Abrams producing unit, north flank, "A" sand reservoir.



"A" SAND



"B" SAND

"C" SAND

FIG. 5.—Photomicrographs of basal Miocene sands "A," "B," and "C." Scale: 1 inch = $\frac{1}{4}$ millimeter.

PRODUCING SANDS

The drilled thickness of the producing basal Miocene sand section of West Columbia ranges from 500 feet in the vicinity of the dome to 700 feet down on the flanks of the dome. It is subdivided into an upper or "A" zone and a lower or "B" zone. The basal sand in the lower zone is referred to on the northern flank as the "C" zone.

The upper or "A" zone, approximately 200 feet thick, is formed of fine- to medium-grained sands with reworked Cretaceous and indigenous marine fauna. The zone has several shale partings on the basis of which it is often subdivided into the upper, middle, and lower "A" sands. Indurated streaks are also present, particularly in the proximity of faults and domal material.

The lower zone is separated from the upper zone by a shale break of 100–150 feet in thickness. The top part of the lower or "B" zone is medium-grained, uniform, clean, soft, or loosely cemented sand with few or no shell fragments present. The "B" zone averages 200 feet of effective sand with a permeability ranging from 2,000 to 15,000 millidarcys.

The basal or the "C" zone, is medium- to coarse-grained sand, not as well sorted as the "B" sand and containing an abundant marine fauna. The effective sand thickness of the "C" sand ranges from 50 to 60 feet. The photomicrographs (Fig. 5) show the characteristics of typical samples of sands "A," "B," and "C."

The figures of effective sand thicknesses, shown in the previous paragraph, are average values. In making computations of recoveries for any particular segment the values used were based on the average shown by the wells drilled in that segment rather than the foregoing field average.

RESERVOIR PERFORMANCE

The production performance of the West Columbia field as a whole is controlled by an effective water drive. This is well illustrated in Figure 6, showing the constant rate of total fluid production (oil and water) of the upper or "A" zone from the northern segment west of the East Abrams fault over a period of 20 years. The monthly rate of total fluid production prior to 1935 averaged 400,000–500,000 barrels per month with no visible sign of decline. The decrease in rate of total fluid production after 1935 is due to proration.

The reservoir-pressure measurements of four key wells, located in the northern segment west of the East Abrams fault, namely, The Texas Company's Abrams No. 1, Abrams No. 6, Hogg No. 63, and Hogg No. 81, showed an average bottom-hole pressure of 1,104 pounds per square inch in 1935 and 1,106 pounds per square inch in 1936. The very slight increase in pressure recorded in 1936 is probably the result of a slight building-up of the reservoir pressure as a result of the prevailing restrictions on production. These pressure measurements represent a pressure decline of only 17 per cent of the original reservoir pressure estimated at 1,330 pounds. The relatively small area under consideration had been producing since July, 1920, at an average rate of 450,000 barrels of fluid per

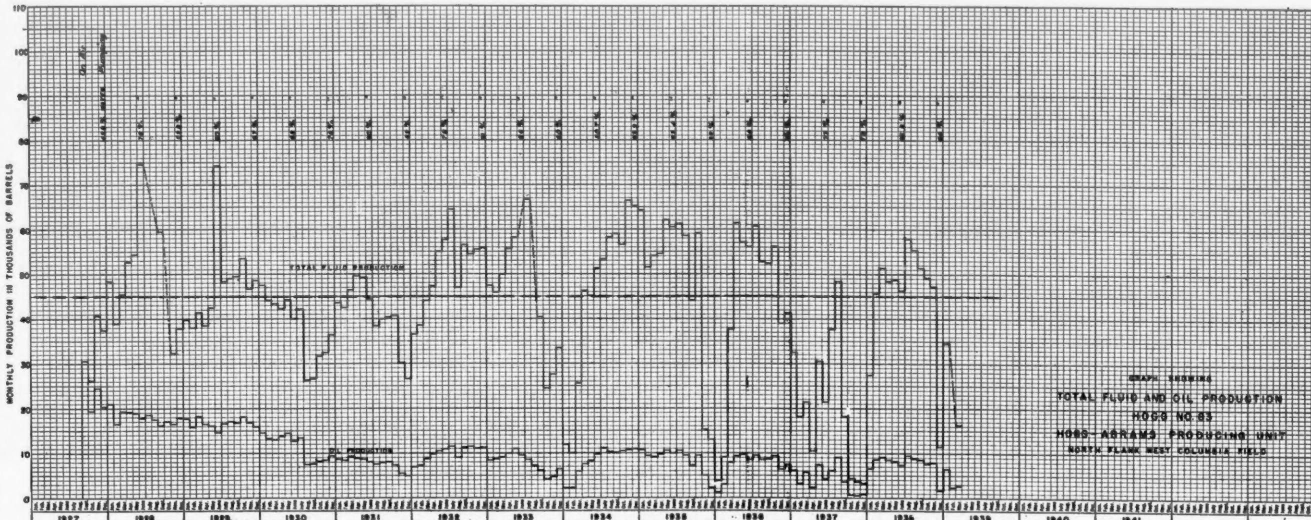


FIG. 7.—Graph showing total fluid and oil production, Hogg No. 83, Hogg-Abrams producing unit, north flank.

month, amounting to more than 78 million barrels of fluid during the period from July, 1920, to January, 1935. This evidence of natural pressure maintenance in the reservoir is undoubtedly the result of an active water drive due to high sand permeability and continuity of fluid migration throughout the segment.

Gas-oil ratio measurements made in 1933 and in 1935 average slightly less than 60 cubic feet of gas per barrel of oil. The normal saturation of West Columbia oil at the prevailing reservoir pressure and temperature was calculated on the basis of laboratory tests at 154 cubic feet per barrel. It is believed that this condition of undersaturation of the oil with gas is the result of regional submergence of the area following the accumulation of oil and is not the direct result of liberation of gas due to a substantial reservoir-pressure drop. Locally, and at various periods of the development of the field, there have been low-pressure areas caused by heavy withdrawals that resulted in a liberation of gas from solution, and there is evidence to that effect in the behavior of some of the wells. However, when taking into account the performance of the field as a whole, there seems to be no evidence of a general pressure drop that could have caused a decrease in gas saturation from 154 cubic feet to 60 cubic feet per barrel.

The average gravity of the oil is 20°–21° Bé. The relatively low gravity and small gas saturation account for the very small volume shrinkage factor of 8 per cent of the oil measured under reservoir and surface conditions.

There is no evidence of the existence of an original gas cap. The discovery well in the lower or "B" zone on the north side of the dome, The Texas Company's Hogg No. 58, located close to the top of the sand, produced oil with normal gas-oil ratio from the very beginning. On the other hand, in the upper or "A" zone there is evidence that the wide-open production of the discovery well, Abrams No. 1, and its offset, Hogg No. 49, caused an evolution of gas from solution in the area surrounding these wells. The subsequent completion of Hogg No. 58 and Hogg No. 80, and other wells located higher on structure, revealed the presence of a gas cap in the producing sand of Abrams No. 1 and Hogg No. 49, which is attributed to accumulation of free gas caused by the production of the latter wells.

The average rate of total fluid production of most wells was constant over their entire producing life, except for the period subjected to proration and imposed mechanical restrictions. A typical oil and total fluid production record of a well producing from the upper zone is shown in Figure 7. The Texas Company's Hogg No. 83 averaged 45,000 barrels of total fluid from 1927 through 1939. Some of the irregularities of production are due to shut-downs and mechanical difficulties, whereas others have to be traced to erroneous recording of the gauge tests of total fluid. It will be noticed, however, that most of the drops in total fluid correspond with drops in oil production, of which there was a fairly accurate daily record. Hogg No. 83 had been pumping almost from the beginning of its producing life. The large pumping capacity of this well is the result of a high fluid level in the reservoir which permits the use of large-diameter pumping units

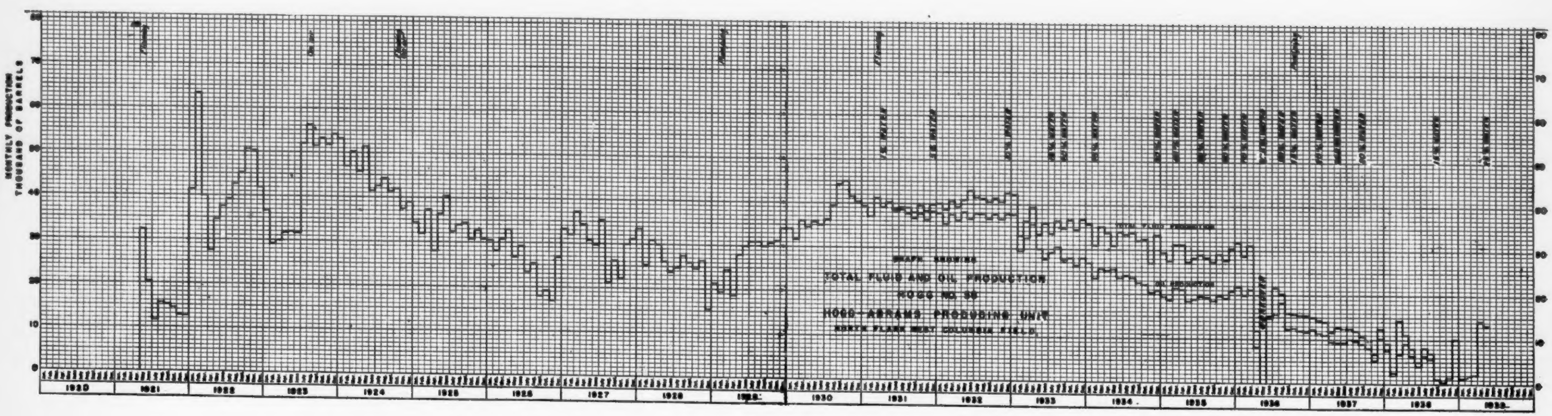


FIG. 8.—Graph showing total fluid and oil production, Hogg No. 58, Hogg-Abrams producing unit, north flank.

submerged at shallow depth, capable of producing large quantities of oil and water.

In the case of flowing wells, the rate of total fluid production shows a decline when the well begins making water because the weight of additional water in the tubing increases the bottom-hole pressure of the well, which in turn reduces the reservoir-pressure differential toward the well. This fact is illustrated in Figure 8, showing the oil and total fluid production record of The Texas Company's Hogg No. 58, located in the northern segment and producing from the lower zone. In this well, it is noticed that, as the percentage of water increased steadily from 1931 to 1936, there was a gradual drop in oil and total fluid production; the well was reworked in 1936. The major drop in production shown in Figure 8, which began in 1924 and extended through 1929, can definitely be traced to production interference as a result of completion of other wells within the radius of drainage of Hogg No. 58. The subject of drainage and well interference will be discussed further.

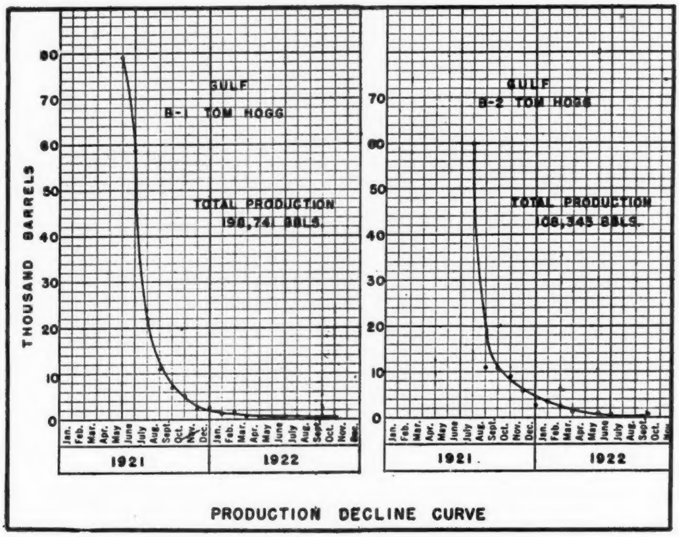


FIG. 9.—Production decline curve, Gulf Refining Company's Tom Hogg B-1 and B-2.

While the constant rate of total fluid production, shown in Figure 6, for the northern segment, and in Figures 7 and 8, for individual wells producing from the upper and lower zones of the basal Miocene sands, was prevalent in the West Columbia field and indicative of an active water drive, there have been several exceptions noted. Most of these exceptions can be traced to the production of

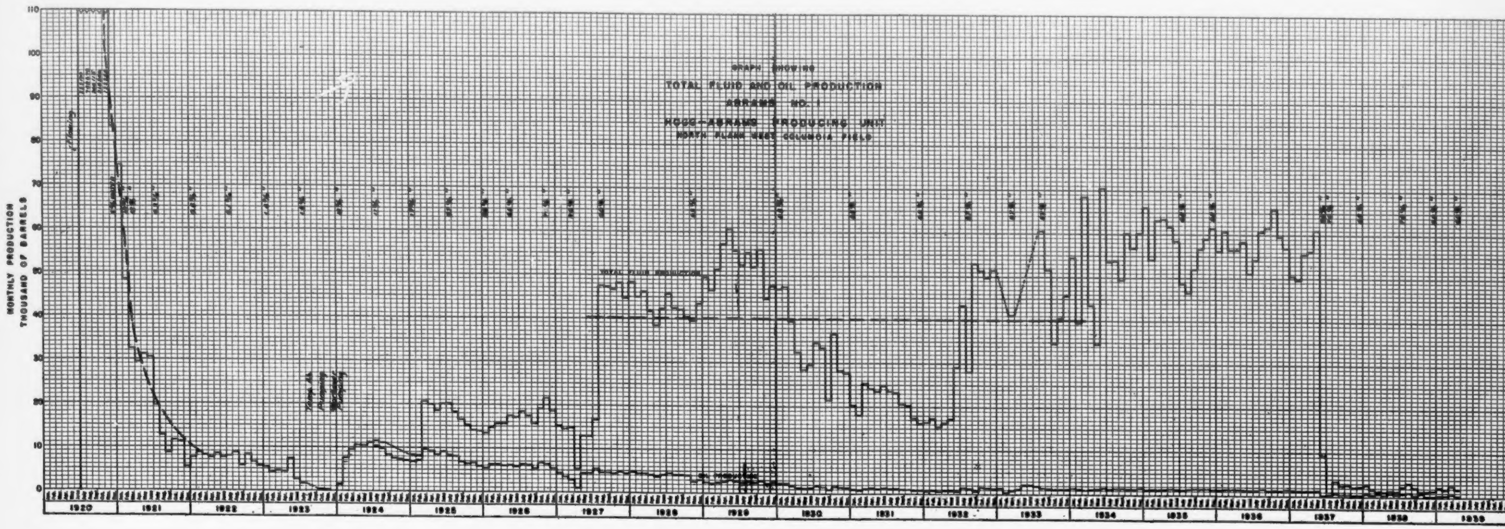


FIG. 10.—Graph showing total fluid and oil production, The Texas Company's Abrams No. 1, Hogg-Abrams producing unit, north flank.

wells drilled close together or being produced at very high rates of flow which caused a drop in pressure of sufficient magnitude to change the type of production from hydraulic drive to volumetric as a result of gas liberation in the surrounding oil reservoir. In the densely drilled area northeast of the dome, the rapid decline and early exhaustion of the wells are shown by the production-decline curves of the Gulf Refining Company's wells, Tom Hogg No. B-1 and Tom Hogg No. B-2 (Fig. 9). The same rapid decline of production was recorded in The Texas Company's discovery well, Abrams No. 1, which was flowing at the rate of 750,000 barrels per month in August, 1921, and 2 years later stopped producing either oil or water, as shown in Figure 10. The well was subsequently reworked and in 1924 began pumping oil at the rate of 10,000 barrels per month with 11–12 per cent water. The percentage of water increased as the rate of total fluid increased and from 1932 to 1937 the well produced at a constant rate of total fluid production, averaging 55,000 barrels per month, with an increased water content of 97–98 per cent. Thus, the same well produced from the same zone under both volumetric and hydraulic flow, as determined by the localized rate of fluid withdrawal from the reservoir.

OIL RECOVERIES

The electrical logging of the entire producing Miocene sand section in several wells recently drilled in the northern segment has made possible a fairly accurate determination of the original oil content of that segment. There are no electrical well logs available in any other part of the old Miocene producing area, and though the drillers' logs are of assistance in correlation work, they show too many discrepancies for the purpose of accurate volumetric measurements. Two methods could be pursued in determining the acre-foot recovery of the segment: (1) by computing the actual acre-foot recovery plus that of future reserves, or (2) by computing the actual acre-foot recovery of the present depleted part of the reservoir. The estimate of volume of depleted sand based on sand data and the position of the water in the reservoir as reflected by the oil-water contacts shown in recent electrical well logs and the percentage of water produced by various wells seemed to be more accurate than the estimate of future reserves, for which reason the second of the aforementioned methods was chosen.

As previously stated, the northern segment has been subdivided into two producing units because of the existence of the prominent East Abrams fault. Recent wells drilled east of this fault indicate lack of production continuity between the two units. The Texas Company's wells, Abrams No. 1 and Abrams No. 11, and Hogg No. 81, located west of the East Abrams fault, were producing oil with a large percentage of water from the upper or "A" zone from a depth of less than 2,900 feet. The Texas Company's Hogg No. 94, drilled east of the fault, produced oil without any water from the same zone at a depth of 3,200 feet. Farther updip, west of the fault, The Texas Company's Hogg No. 92 had an oil-water contact at 2,770 feet, and east of the fault the company's Hogg No. 93

is producing oil without any water from the same zone at a depth of 2,980 feet.

Because the eastern part of the northern segment has not been depleted to as large an extent as the western part, the computation of recoveries is confined to the latter area, as shown in Table I.

TABLE I

RECOVERIES OF OIL PER ACRE FOOT OF EFFECTIVE SAND IN WESTERN PART OF NORTHERN SEGMENT OF WEST COLUMBIA FIELD, TEXAS

Description	*Upper Zone Sand "A"*	*Lower Zone Sand "B"*
Surface of depleted area in acres	175.86	105.17
Number of producing wells	37	6
Well density in acres per well	4.6	17.5
Average effective sand thickness in feet	147.0	175.0
Average effective sand thickness above original water level	113.12	131.49
Volume of depleted oil sand in acre feet	19,893	13,829
Recovery to January 1, 1940, in barrels	22,099,334	15,508,829
Recovery in barrels per acre foot of sand depleted	1,110	1,121

The "C" or basal sand of the lower zone was not included in the foregoing computations because production from this sand had only been established during the past 3 years, and, at restricted withdrawals due to proration, only a small percentage of its content has been depleted.

The computations of recoveries of oil per acre foot of sand depleted show practically the same value for both sands although the well densities had a ratio of almost 4 to 1.

The high recoveries at West Columbia are due to several factors; good porosity, averaging 28 per cent; small volume shrinkage factor; high permeability, allowing for a wide area of drainage; high reservoir pressure, permitting the oil to flow toward the wells under the action of an effective pressure differential; and an effective water-drive action over a long period of time.

WELL SPACING

It has been shown in the preceding paragraphs that the recoveries per acre foot of sand for the two producing zones of the same segment were practically the same for an average spacing of 4.6 acres per well and 17.5 acres per well. The wider spacing corresponds with an average radius of drainage of 492 feet. It will be shown in the following paragraphs that experimental data as well as the analysis of production data show positive evidence of drainage over distances that equal or exceed the average radius of drainage of the wider-spaced wells.

On September 14, 1932, an aqueous solution of fluorescein dye was introduced in The Texas Company's Hogg No. 64, in the western part of the northern segment. The two updip wells, Hogg No. 63 and Hogg No. 70, producing from the same sand, were carefully watched for the first appearance of the dye. The location of the wells with regard to each other and their position on structure is shown in Figure 11. Hogg No. 97, shown in the sketch, had not been completed

at the time of the dye-travel experiments. The dye was first recorded in Hogg No. 63, located at a distance of 420 feet, after a lapse of 161 days, and in Hogg No. 70, located at a distance of 800 feet, after a lapse of 180 days. These results show positive evidence of migration of fluid over the distances mentioned. It is interesting to note that the rate of updip migration toward Hogg No. 70 was approximately 70 per cent faster than the rate of lateral migration toward Hogg No. 63.

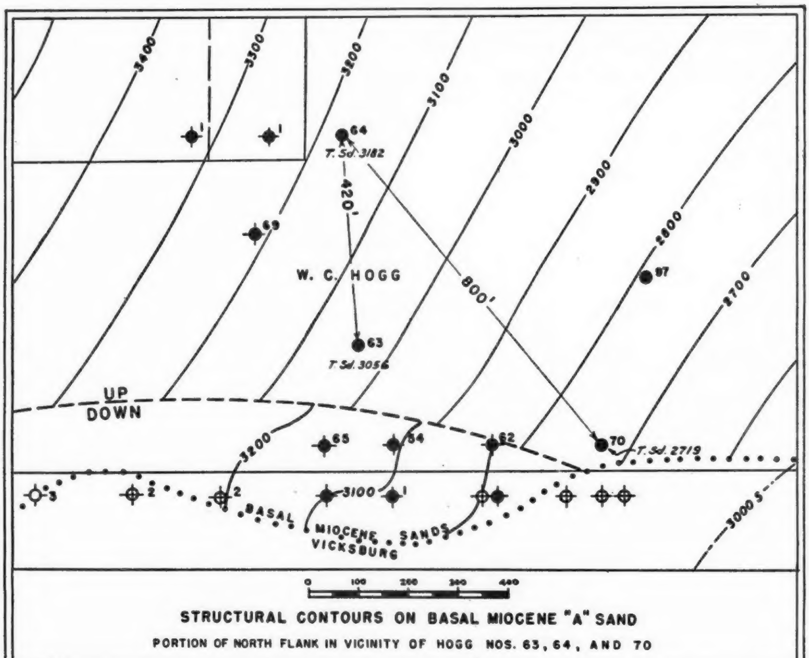


FIG. 11.—Structural contours on basal Miocene "A" sand, part of north flank in vicinity of Hogg Nos. 63, 64, and 70.

Additional evidence of drainage within the reservoir is furnished by studies of production interference between wells. The movement of fluid in a reservoir is in the direction of decreasing pressures. Although, as a general rule, the prevailing direction of movement in a water-driven field is updip, migration may occur in any other direction with regard to structure. The three actual examples, described in the following paragraphs, show by way of well interference, positive evidence of drainage in an updip, a lateral, and a downdip direction, depending on rates of fluid withdrawals and pressure differentials created in the reservoir.

The production behavior of The Texas Company's Hogg No. 68 and Hogg

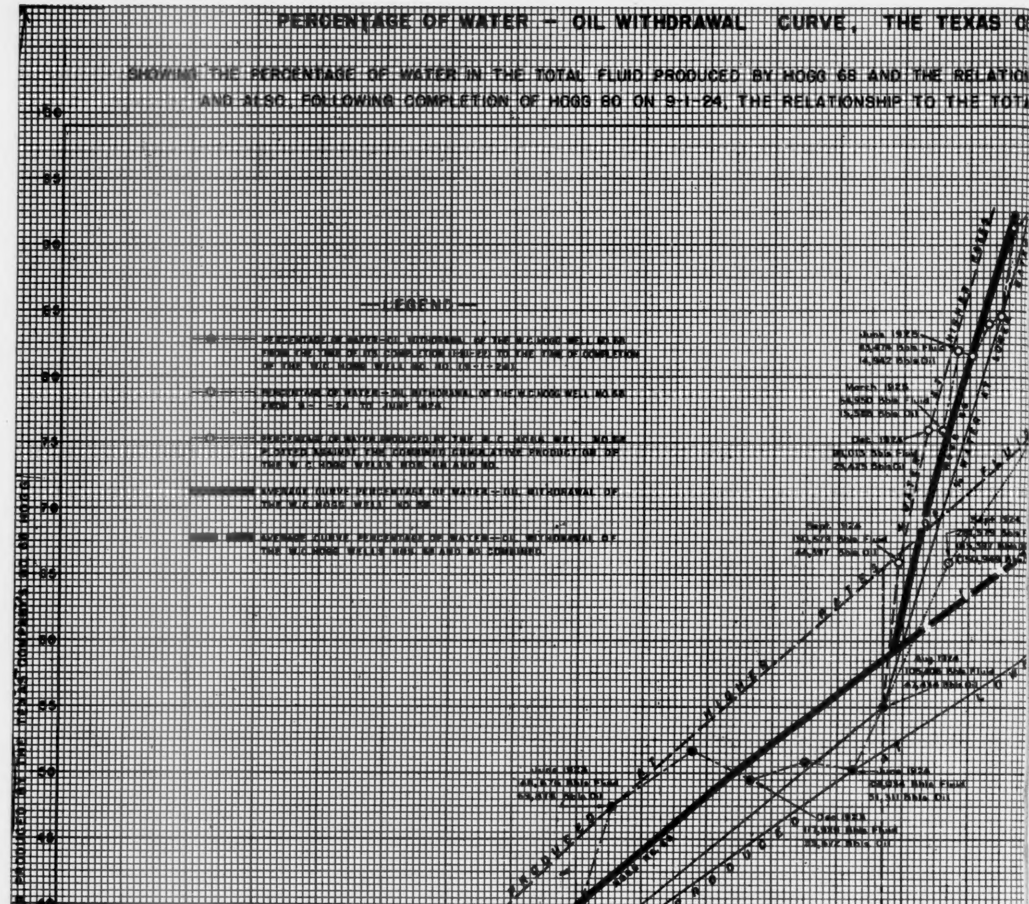
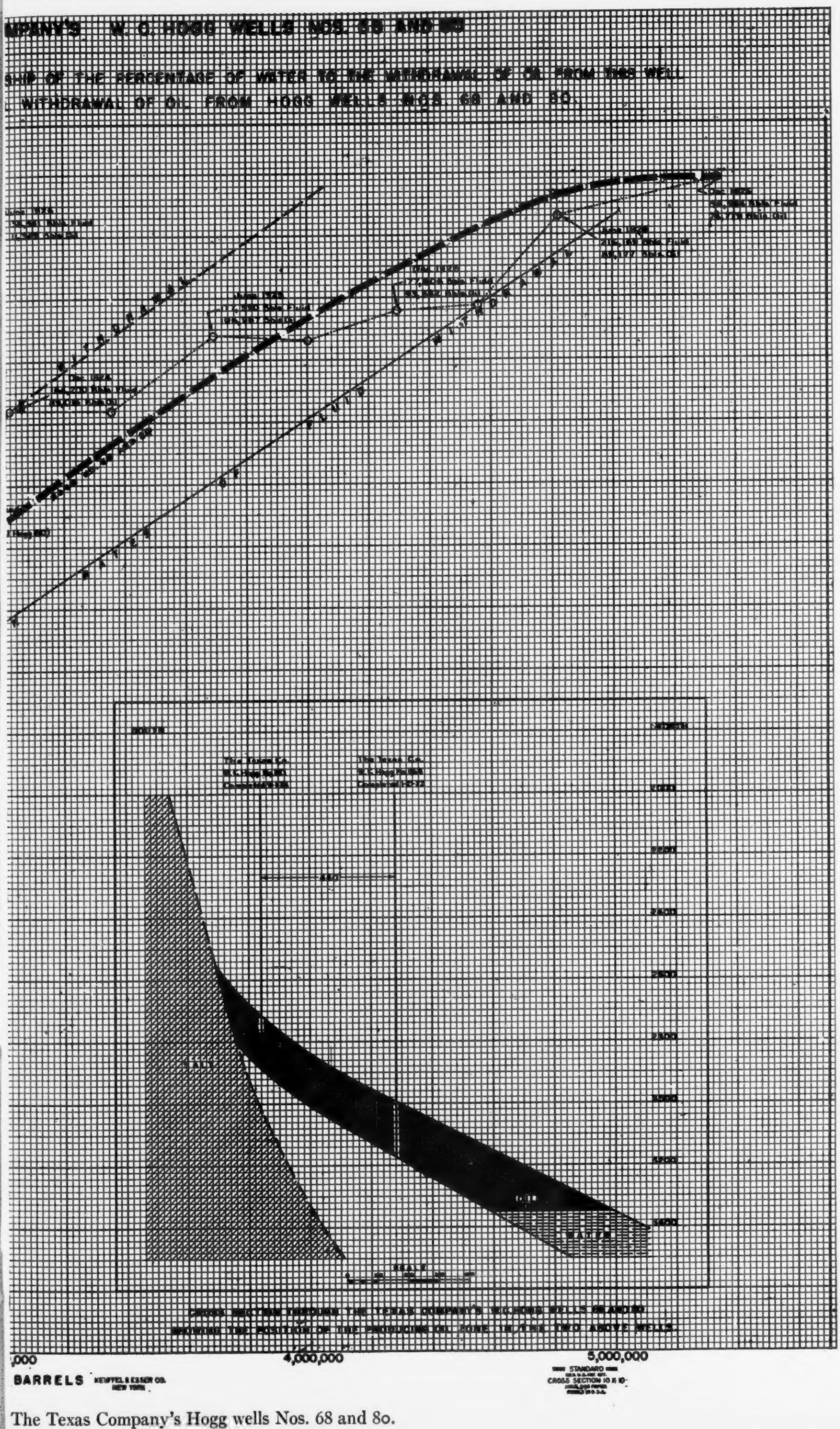


FIG. 12.—Percentage of water-oil withdrawal curve,



The Texas Company's Hogg wells Nos. 68 and 80.

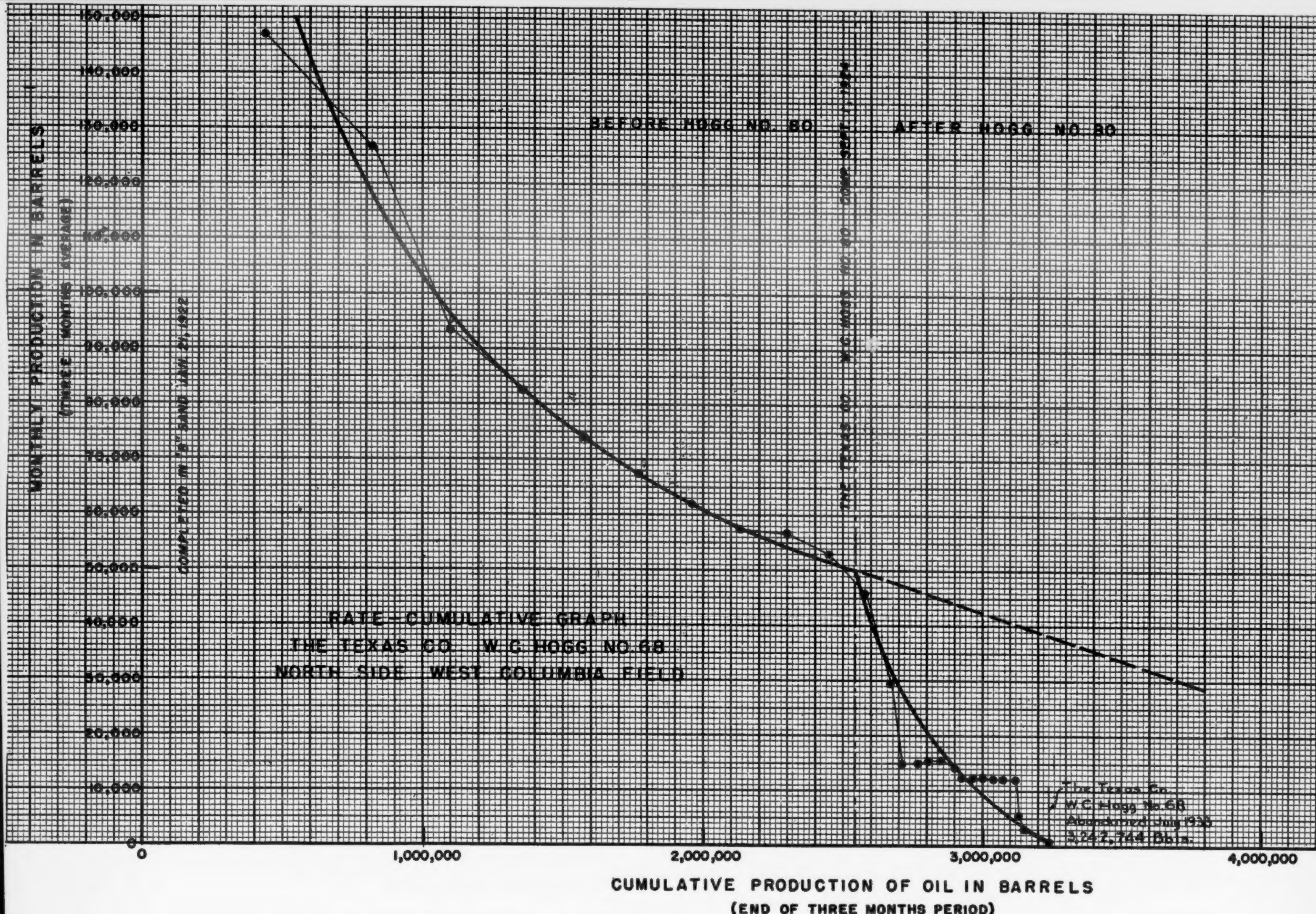


FIG. 13.—Rate cumulative graph, The Texas Company's W. C. Hogg No. 68, north side.

No. 80 is an example of updip interference. Both wells produced from the lower or "B" zone and are located in the northern segment west of the East Abrams fault. The relative position of the two wells is shown in the lower right corner of Figure 12. A fault which cuts the upper or "A" zone between the two wells is shown on the structural map of the upper zone (Fig. 2). The interference of the updip well, Hogg No. 80, with the production of the downdip well, Hogg No. 68, is shown in Figs. 12 and 13. The latter figure is a rate cumulative graph, showing a very definite change in rate of decline corresponding with the completion of Hogg No. 80 in September, 1924.

Figure 12 shows the volumetric relationship of oil withdrawal to water encroachment which in a water-driven field is a fundamental principle. The rate of water encroachment, shown on the vertical scale by the percentage of water produced by the flowing well, Hogg No. 68, is plotted against the total volume of oil withdrawn by the well from the reservoir. The relationship of water encroachment to oil withdrawal is very uniform except for seasonal variations in rate of flow causing corresponding variations in the percentage of water produced as a result of water coning in the well. These variations are shown on the sketch. In September, 1924, Hogg No. 80 was completed in the same sand and produced oil from the same area as Hogg No. 68. The relationship of the combined withdrawal of oil of the two wells with regard to the rate of water encroachment remains the same, as shown in Figure 12 by a heavy dashed line. The relationship of production of Hogg No. 68 with regard to the rate of water encroachment shown by a heavy line in Figure 12 exhibits a definite change in trend corresponding with the completion of the updip well, Hogg No. 80.

The production behavior of The Texas Company's Abrams No. 6 and Hogg No. 82 shows an example of lateral drainage. The two wells are located in the northern segment, 500 feet apart, and were producing from the upper or "A" zone. Abrams No. 6 was completed on January 1, 1922, at 2,872–2,943 feet and Hogg No. 82 was completed on October 24, 1926, at 2,903–2,976 feet. The interference of Hogg No. 82 with the production of Abrams No. 6 is shown in Figure 14. Corresponding with the completion of Hogg No. 82, the graph shows a small drop in the average total fluid production of Abrams No. 6. During the latter part of 1928, when the total fluid production of well No. 82 was increased to a rate exceeding 100,000 barrels of fluid per month, the total fluid production of Abrams No. 6 dropped to less than 10,000 barrels per month, as compared with an average of 15,000 barrels prior to the completion of well No. 82. The reduced total fluid production of Abrams No. 6 prevailed during the entire period of increased production of well No. 82. During 1931, when the production of the latter well was curtailed to less than the 100,000-barrel-per-month level, the production of Abrams No. 6 began to increase and in 1932 reached its original level of 15,000 barrels per month. During June, 1932, the production of well No. 82 took a sudden plunge from 60,000 barrels per month to 20,000 barrels per month and during the same month the total fluid production of the Abrams

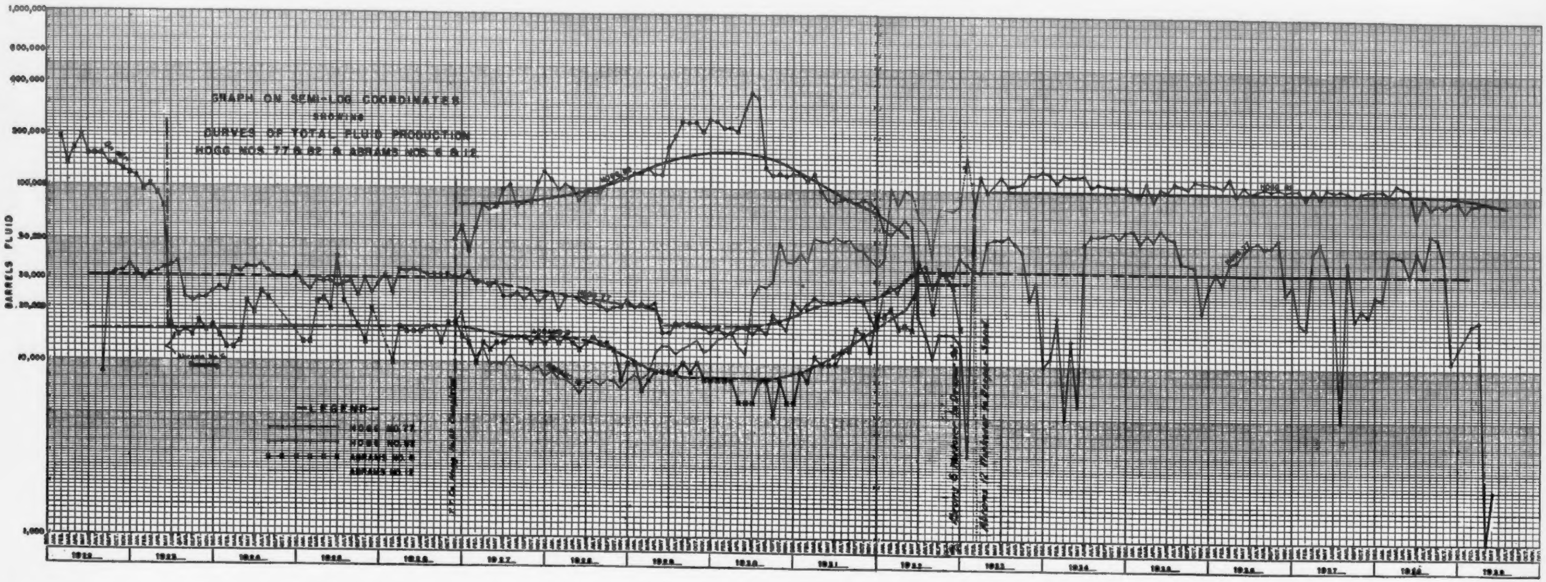


FIG. 14.—Graph on semi-log coördinates, showing curves of total fluid production, Hogg Nos. 77 and 82 and Abrams Nos. 6 and 12.

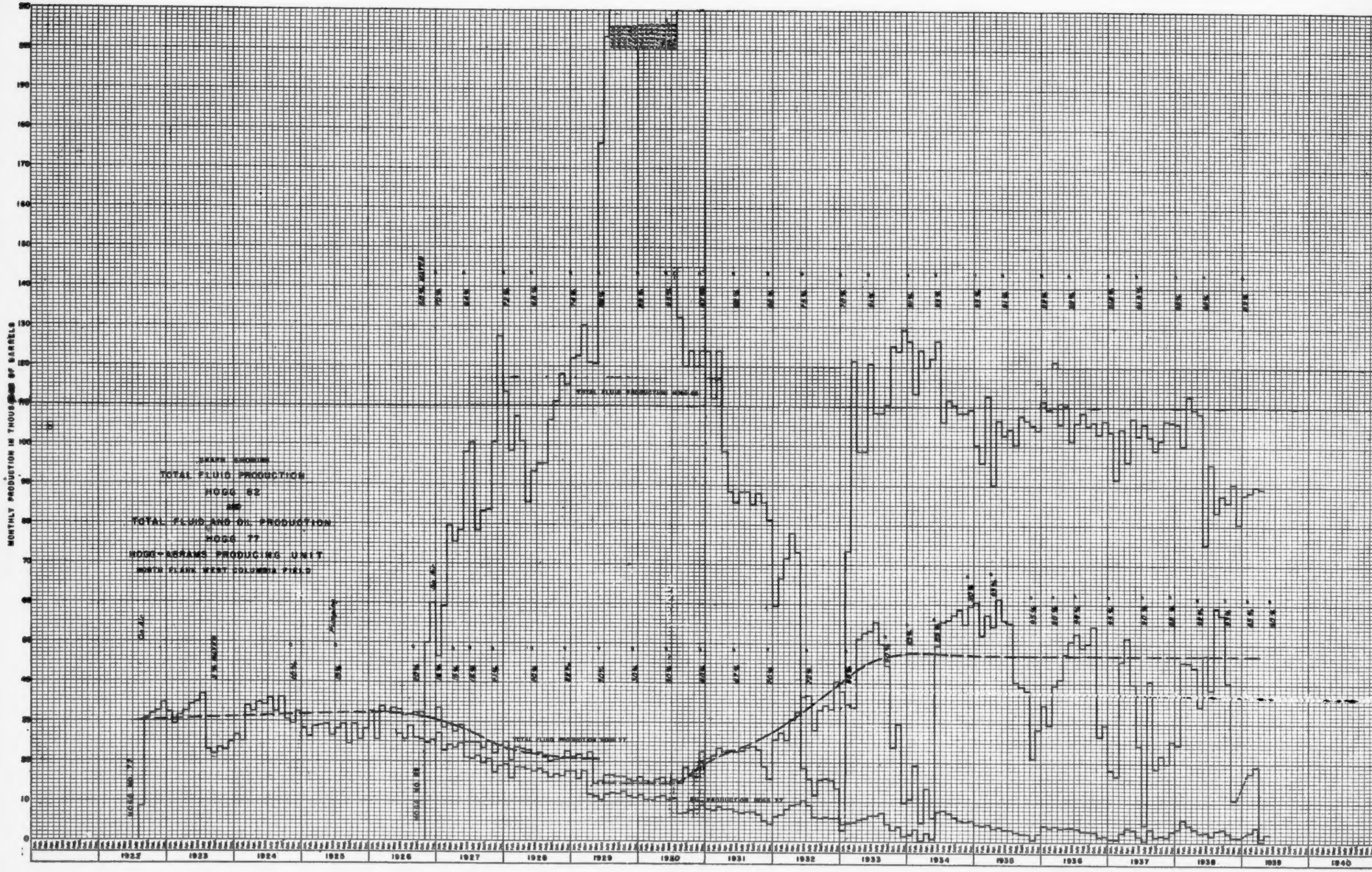


FIG. 15.—Graph showing total fluid production, Hogg 82, and total fluid and oil production, Hogg 77, Hogg-Abrams producing unit, north flank.

well increased from 15,000 to 40,000 barrels. During the latter part of the year, Abrams No. 6 was reworked and recompleted in a deeper sand.

The production behavior of The Texas Company's Hogg No. 77 and Hogg No. 82 is offered as an example of downdip drainage. The two wells are located in the northern segment, 400 feet apart, and were producing from the upper or "A" zone. Hogg No. 77 was completed on July 26, 1922, at 2,798–2,851 feet and Hogg No. 82, as previously shown, was completed on October 24, 1926, at 2,903–2,976, the first well being located more than 100 feet higher structurally. The production behavior of well No. 77, shown in Figs. 14 and 15, is very similar to that of Abrams No. 6, showing similar drops in production as a result of the completion of Hogg. No. 82, with a minimum rate of total fluid production corresponding with the maximum rate of flow of the latter well and a pick-up in rate of flow corresponding with the decline in total fluid production of well No. 82.

Figure 14 also shows the total fluid production record of Abrams No. 12, producing from the same sand and located downdip from Hogg No. 82. The graph illustrates very clearly the effect of drainage produced by the heavy withdrawals of fluid through Hogg No. 82 on surrounding wells, whether such wells were updip, downdip, or lateral. Hogg No. 82, producing by airlift at high rates of flow, caused a differential pressure in the reservoir toward the well with the consequent interference effects aforementioned.

Under ordinary operating conditions, pressure differentials in the reservoir are relatively small and production interference phenomena are difficult to segregate from the normal variations in production recorded by wells. However, pressure differentials will always be present whenever oil is being withdrawn from a reservoir and such pressure differentials will cause migration of oil from areas of high pressure to areas of low pressure, similar to those here recorded.

CONCLUSIONS

The oil recovery of a large producing unit of the West Columbia field was 1,121 barrels per acre foot of sand for a spacing of one well to 17.5 acres. Practically the same recovery was obtained for a spacing of one well to 4.6 acres, showing that within these limits the recovery per acre foot of sand is independent of well spacing. Dye-travel experiments proved the migration of fluid in the reservoir over a distance of 800 feet updip and 420 feet laterally, though these figures would in no way establish a minimum limit of migration. Production interference between wells was established over distances of 400–500 feet.

The fact that the high recovery of 1,100 barrels per acre foot of sand depleted, obtained from a well spacing of 17.5 acres per well, was not exceeded by recoveries of much denser spacing and the evidence of well interference over distances of 400–500 feet, with further evidence of drainage to 800 feet, leads to the conclusion that the West Columbia field would have been properly drained under a uniform wider spacing program of at least 17.5 acres per well.

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SCHULER FIELD, UNION COUNTY, ARKANSAS[1]

WARREN B. WEEKS[2] AND CLYDE W. ALEXANDER[2]
Shreveport, Louisiana

ABSTRACT

The Schuler field, 18 miles west and south of El Dorado, Arkansas, was discovered on April 6, 1937, by the Lion Oil Refining Company and Phillips Petroleum Company's Edna Morgan No. A-1, Sec. 18, T. 18 S., R. 17 W. The field is on an anticline on a southeastward-plunging Upper Cretaceous nose. The deeper structure was determined by seismic exploration by the Phillips Petroleum Company, who commenced the discovery well. The well was later deepened and completed in partnership with the Lion Oil Refining Company.

The first well was completed at a depth of 5,559 feet, in a sand which was found to be the upper of several lenticular producing sands lying within a zone of 500 feet near the top of the Cotton Valley formation of Mesozoic age. Of the 15 wells completed in this Morgan Sands zone, four have since been deepened. The zone produced 2,141,040 barrels to July, 1941.

E. M. Jones *et al.* found deeper production in September, 1937, at a depth of 7,616 feet in a sand at the base of the Cotton Valley formation. This Jones sand, with an average thickness of 65 feet, is productive over a much greater area than is the upper zone. Approximately 4,000 acres had been proved for production by July 1, 1940. By July 1, 1941, this sand had produced 18,542,590 barrels of oil from 146 wells.

The original discovery well was deepened and recompleted on October 22, 1937, at a depth of 7,688 feet, as a gas and distillate well from still a third zone, the Reynolds oölite of the Smackover limestone. By the end of that year this well had produced 34,028 barrels of distillate and 800 million cubic feet of gas. In March, 1938, the Marine Oil Company completed the Justiss No. 4 as an oil well in this zone. Subsequently, by July 1, 1941, this oölite zone had produced a total of 2,766,280 barrels of oil from 16 wells.

On June 22, 1941, the Phillips Petroleum Company *et al.* Leona No. 1 was recompleted, pumping 70 barrels of oil per day from the Leona sand at 6,922 feet, after having been plugged back from the Reynolds oölite. By the end of the year two other wells had been completed in this sand.

INTRODUCTION

LOCATION

The Schuler field, comprising approximately 4,000 acres, is located around Sec. 18, T. 18 S., R. 17 W. in central western Union County, Arkansas. The center development of the pool is 14 miles west and 3 miles south of the town of El Dorado, and about 4 miles south of the paved U. S. Highway No. 82, which extends east and west between El Dorado and Magnolia. Figure 1 is a map of the south part of Arkansas, showing the location of the Schuler field relative to the older and shallower producing areas, as well as to the other 6 deep Smackover limestone-producing areas, the Rodessa extension and Stamps field, producing from the Rodessa formation, and the Fouke field, producing from the Paluxy

[1] Read by title before the Association at New Orleans, March 16, 1938. Manuscript received, December 12, 1941. This manuscript was prepared in July, 1940, and all maps and charts are carried only to that date. Subsequent production and pressure data to July, 1941, were added to tables and inserted in the text. No attempt was made to discuss the action of the Jones reservoir subsequent to unitization on February 15, 1941, as it is felt that this should be more completely covered in a reservoir-study paper at some future date.

[2] Geologist, Phillips Petroleum Company. Acknowledgment is given to C. O. Stark and D. E. Lounsbery, of the Phillips Petroleum Company, Bartlesville, Oklahoma, for premission to publish this paper. Many data were obtained from members of the engineering and geological staffs of the Phillips Petroleum Company, the Lion Oil Refining Company, and the Arkansas Oil and Gas Commission.

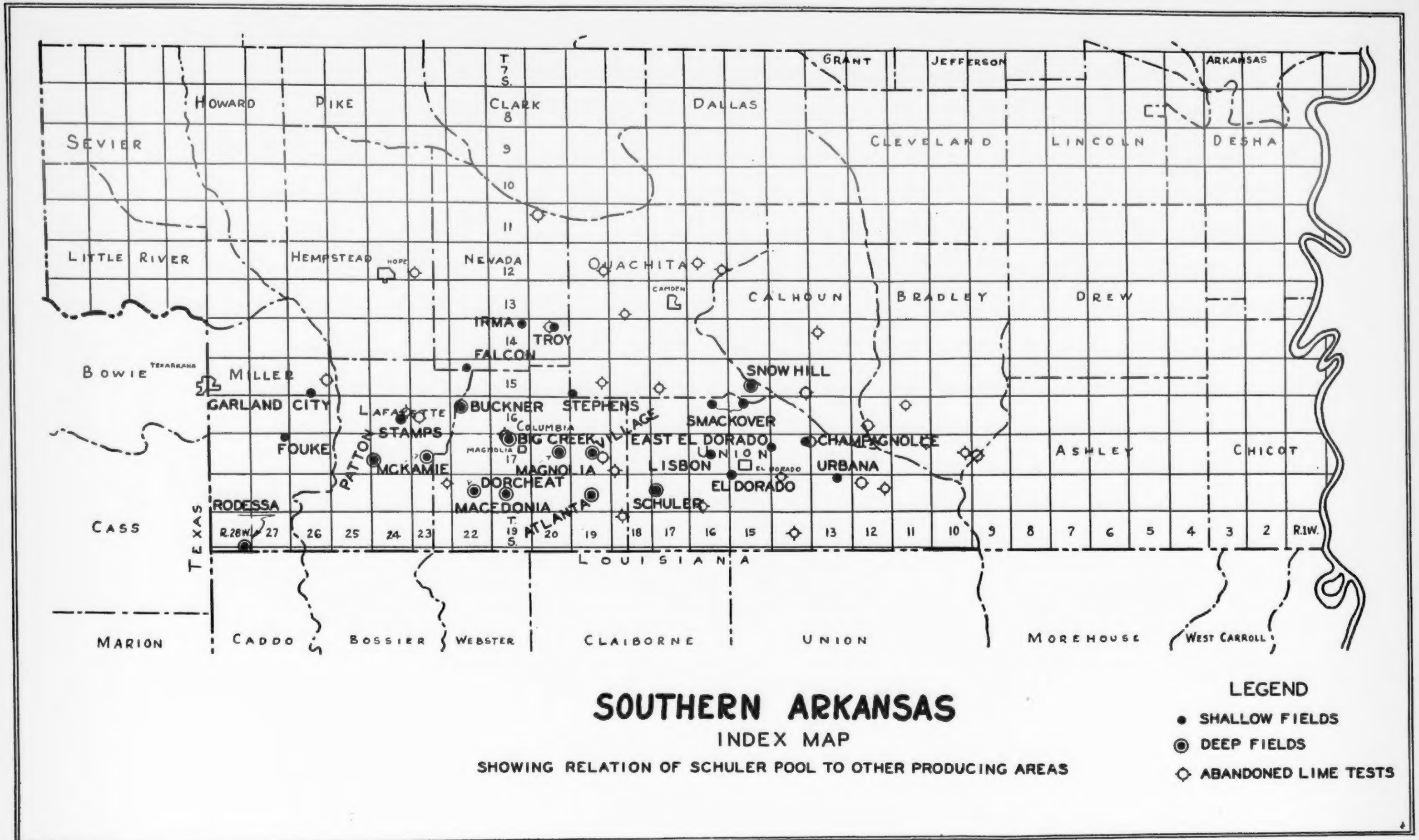


FIG. 1.—Map of southern Arkansas, showing location of Schuler field with regard to older and newer fields and recent deep dry tests.

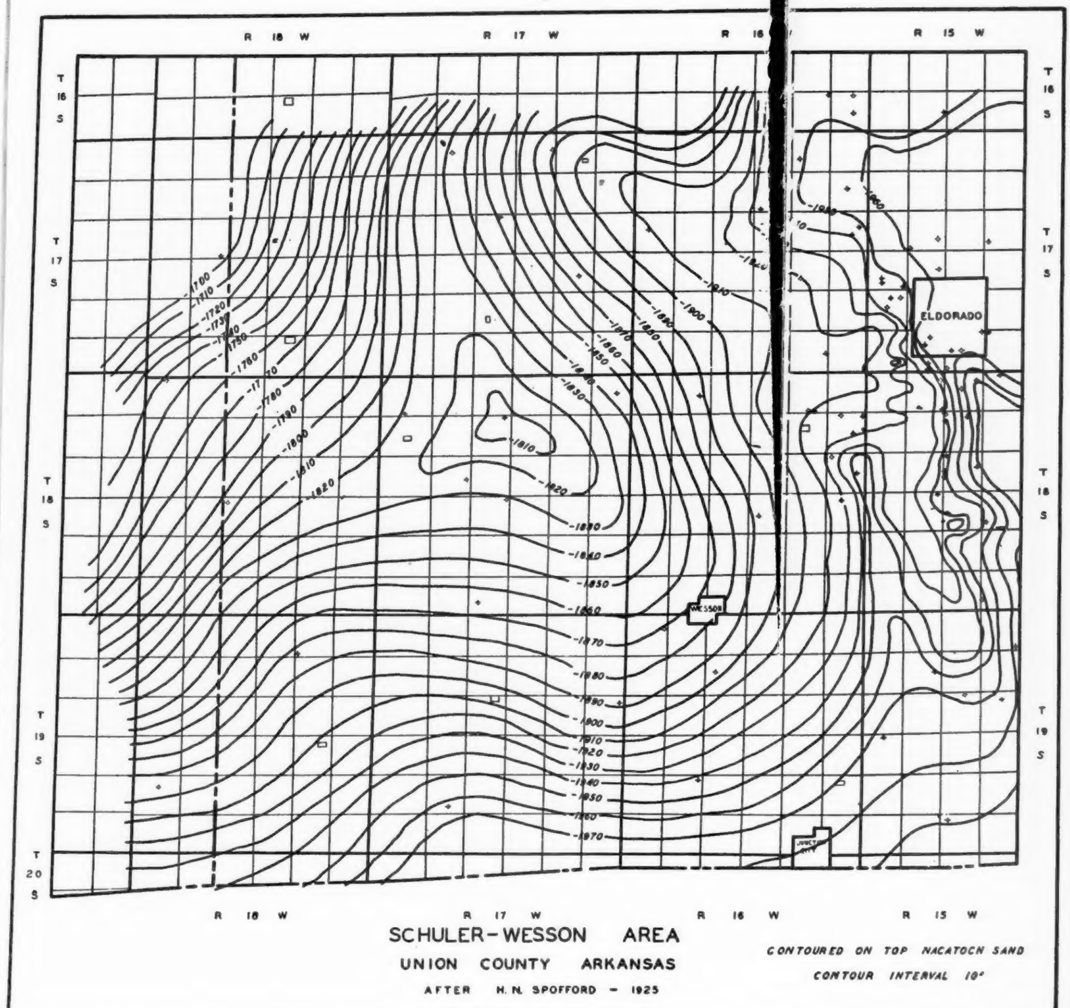


FIG. 2.—Early structural map of Schuler-Wesson area, Union County, Arkansas (after Spofford, 1925).

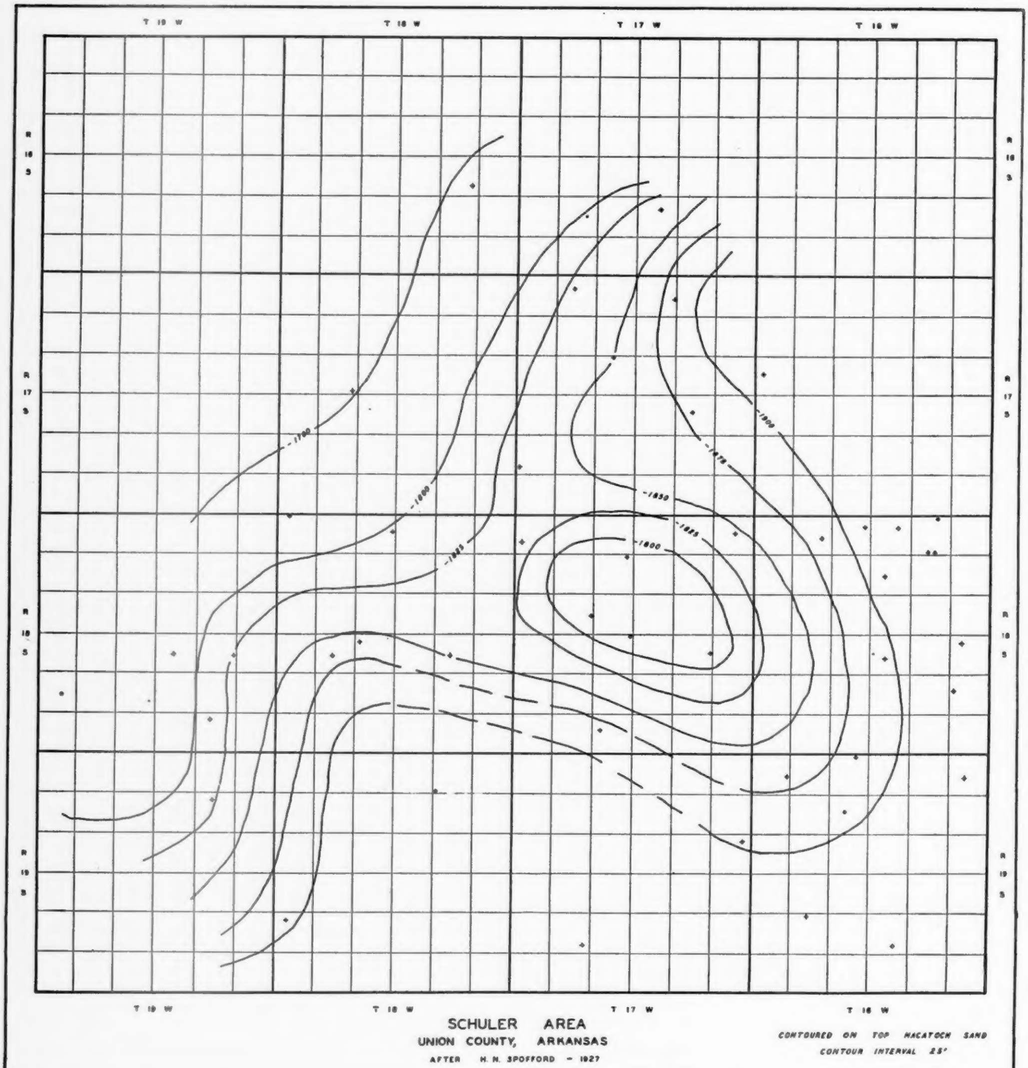


FIG. 3.—Early structural map of Schuler area, Union County, Arkansas (after Spofford, 1927).

formation. This map also shows the position of the wells which have penetrated the Smackover limestone, deepest producing zone at Schuler, and found it "dry."

HISTORY OF DEVELOPMENT

The first well to be drilled in T. 18 S., R. 17 W., Union County, Arkansas, was the Forest Oil Company's Mayfield No. 1 in the northeast corner of Section 21, drilled to 2,910 feet in 1920. Eight more wells had been drilled in that township by 1930. Only one of these wells penetrated beds below the Gulf series. This well, the Calgo Oil Company's Primm No. 1, in Section 9, was drilled to 4,385 feet, penetrating the top part of the Hosston redbed formation. Figures 2 and 3 show an early interpretation of the subsurface structure of this area by H. N. Spofford (8), both before and after the Calgo well was drilled.

The correlation of these and other near-by wells, drilled during this period, definitely established the presence of a long southeastward-plunging nose in the Gulf series formations. This nose extended from the vicinity of Wesson in Sec. 33, T. 18 S., R. 16 W., to the southeast part of T. 17 S., R. 18 W., as shown by Spooner (9) in 1935. However, there had been no showings for commercial oil production in the wells which penetrated the Gulf series along the axis of this nose. No further tests were drilled in this area prior to the year 1936.

In the spring of 1936, after the area had been blocked by associates, the Phillips Petroleum Company made a survey of the area with seismograph instruments. Finding evidence of favorable structural conditions in the subsurface beds, the Lion Oil Refining Company and the Phillips Petroleum Company drilled their Edna Morgan well "A" No. 1 between July 30, 1936, and March 18, 1937. Oil-bearing sand was encountered at 5,536 feet, 140 feet below the top of the Cotton Valley formation. The Morgan well was completed at the depth of 5,559 feet on April 6, 1937, flowing through $9\frac{5}{8}$-inch casing set at 5,555 feet, first producing 60 barrels of 41° gravity oil per hour. As gas broke in from the upper part of the sand, the gravity of the oil changed to 48°.

Subsequently, during 1937, 14 wells were drilled and produced from this and other lenticular sands ranging to the depth of 6,000 feet. Three of these wells were later deepened. Five wells found no production in this zone and were temporarily abandoned. It became apparent that the areal extent of the production from this Morgan Sands zone would be little more than a full section. The gas from the sands was quickly dissipated and the production dropped rapidly. One well was pumping by October, 1937, and all of these wells were on artificial lift by June, 1938. Another pumping well was completed in this zone in February, 1940.

In July, 1937, E. M. Jones *et al.* commenced drilling their Marine Oil Company well No. 1, in the SE. $\frac{1}{4}$ of Sec. 17, T. 18 S., R. 17 W. This well was dry in the Morgan Sands zone and the operators decided to deepen the well to the Smackover limestone. The well was cored into an oil-saturated sand at 7,553 feet, and to the total depth of 7,615 feet, ending in black asphalt-bearing sand after

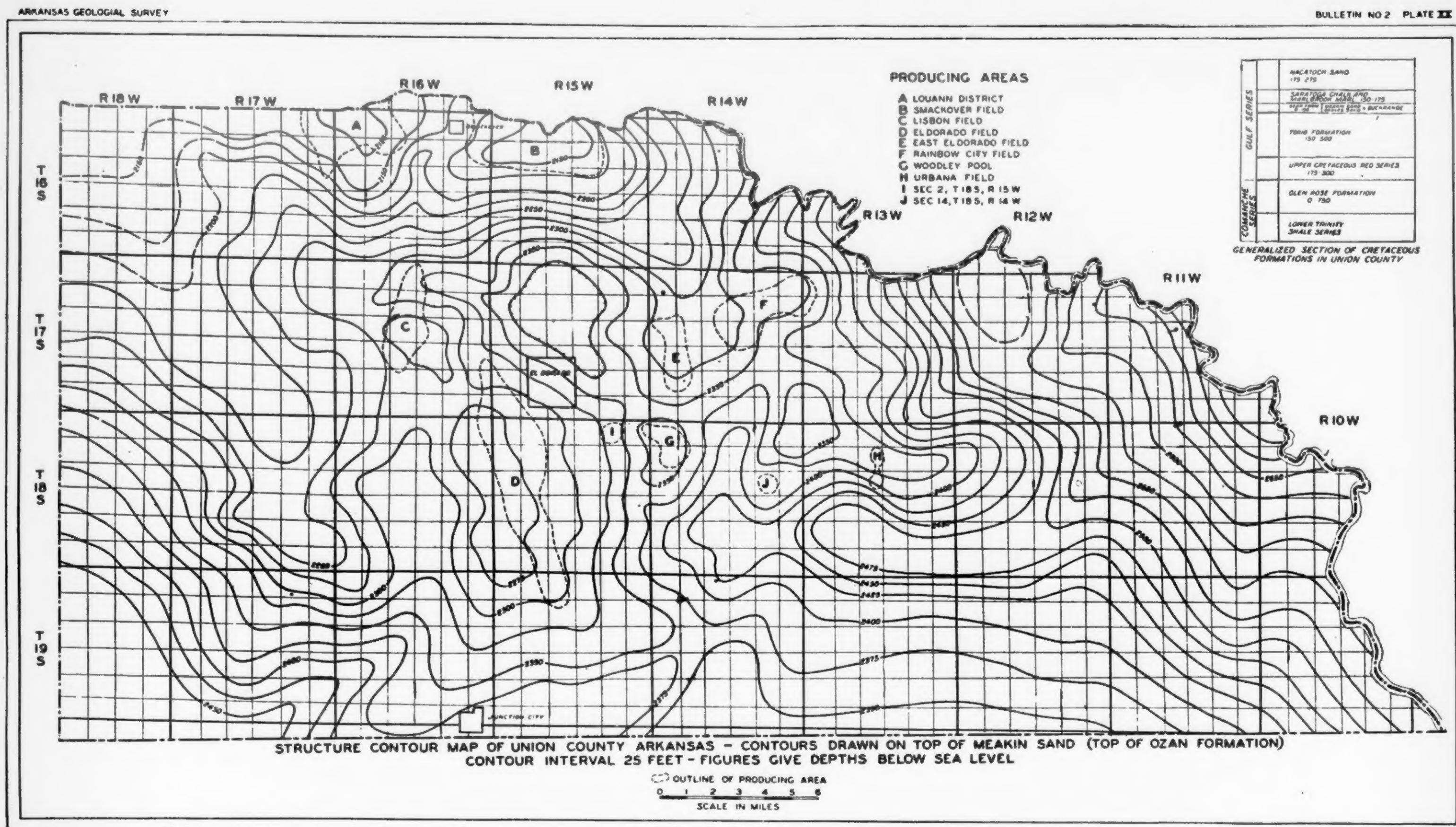


Fig. 4.—Early structure-contour map of Union County, Arkansas (after Spooner, 1935).

encountering a total of 48 feet of oil sand. The well was completed on September 17, 1937, producing from this Jones sand. The initial production was 2,500 barrels of oil and a small percentage of water per day. Later the water was successfully shut off with cement. By July 1, 1940, there were 146 wells producing from this sand, and 3 dry holes had been drilled.

Meanwhile, the original Morgan Sands zone discovery well stopped flowing and between August 19, 1937, and October 22, 1937, this well was deepened to 7,688 feet. Although the Jones sand was cored, the well was drilled on down into the porous oölitic section in the Smackover limestone. Strong gas odor and some light oil stain were encountered in the upper 50 feet of the porosity, and the well was completed from perforations near the top of this zone as a gas-distillate well. It was not until the first of March, 1938, that a north offset, the Marine Oil Company's Justiss No. 4, was completed to prove oil production from this zone. By the end of May, 1939, there were 16 wells producing from this zone.

Although well cuttings and electric logs indicated oil showings in various lenticular sands in the lower part of the Cotton Valley formation, there were few attempts to core these sands. Early in 1941, the Phillips Petroleum Company *et al.* attempted to recomplete Leona No. 1, Sec. 7, T. 18 S., R. 17 W., former Jones sand well, within the Reynolds oölite. Failing this, the lower formations were plugged off and casing was perforated from 6,922 to 6,928 feet where the well was completed, pumping 80 barrels of 47° gravity oil per day. Subsequently one other well was recompleted in this Leona sand and another well drilled. The third well was completed, flowing 400 barrels of oil per day through a small tubing choke.

In February, 1941, 140 of the 146 Jones sand wells went under unit operation. High gas-oil ratio wells were shut in and pressure was allowed to equalize across the field. On July 1, 1941, operators of the unit began returning gas to the Jones pool to partially maintain pressure.

STRATIGRAPHY

SURFACE

The fine to coarse sands, silts, and sandy clays of the upper part of the Claiborne group (Cockfield formation) are exposed in the Schuler area. There are no good exposures, with the formation only manifest in the sandy soil predominant throughout the low, rolling, timbered land which has a relief of approximately 80 feet. The Three Creek bottom, trending north and south through the central eastern part of the field, has the lowest elevation, approximately 200 feet above sea-level. The surrounding low hills rise to only 280 feet above sea-level.

SUBSURFACE

The subsurface stratigraphy is indicated by Figure 5, columnar section showing the general stratigraphy of the field. The known strata present at Schuler consist of the Tertiary system, represented by the lower three groups of the Eocene series; and the Mesozoic system, represented by a full section of the Gulf series

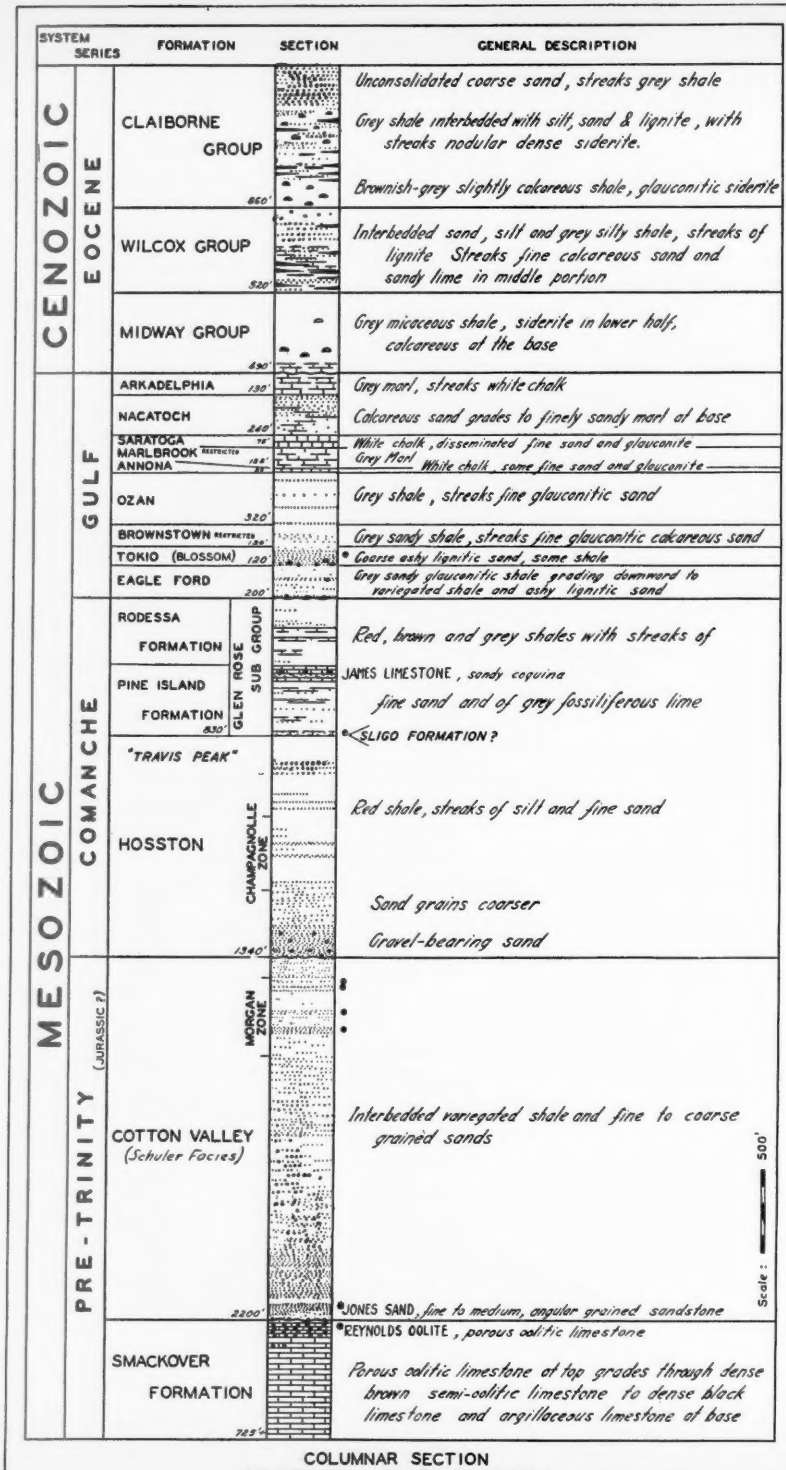


FIG. 5.—Generalized columnar section, Schuler field.

and the lower part of the Comanche series, underlain by two formations (Cotton Valley formation and Smackover formation) of probable Jurassic age (7, p. 20). The deepest well in the field has penetrated 725 feet of Smackover limestone.

The regional unconformity between the Eocene and the Gulf series is not apparent from subsurface information. The minor unconformity between the Tokio and Eagle Ford formations in the Gulf series is marked by a gravel bed of vari-colored chert. The very pronounced regional unconformity at the base of the Gulf series is marked by chert and quartz pebbles, as well as by the absence of a considerable section of the underlying Comanche beds.

Comanche beds immediately underlying the Gulf series belong to the Rodessa formation. Comanche strata which are absent at this locality, due to the widespread regional post-Comanche erosional truncation, include the Washita and Fredericksburg groups, Paluxy formation, Mooringsport formation, and the Ferry Lake anhydrite (middle Glen Rose formation). At Schuler, the Comanche section was truncated to approximately 200 feet below the base of the anhydrite.

That the Hosston formation (7) lies unconformably on the Cotton Valley formation is indicated by the plentiful gravel pebbles in the basal sands of the former. The lower formation actually shows evidence of regional truncation northward from Schuler into Hempstead County. The unconformity between the Cotton Valley formation and the Smackover limestone is marked by a thin bed of gravel, and the marked lithologic change from "non-marine" sands and silts to limestone. Whether there has been appreciable truncation of the limestone is not known. The relatively thin section of dense limestone cap, compared with that of the Magnolia-Village area, may indicate truncation.

The Buckner red shale and anhydrite formation, which apparently lies conformably above the Smackover limestone in the Magnolia-Village area is not present at Schuler. It is the opinion of the writers that it was removed by local erosion prior to Cotton Valley deposition. In this case, it is apparent that there must have been marked structural movement at this locality before Cotton Valley deposition. There are two other current theories regarding the absence of the Buckner formation at Schuler.

1. "The area was an island during the time of Buckner deposition." Evidence for this possibility lies in reports of an unconformity between the Buckner formation and the Smackover limestone, as indicated by conglomeratic material reportedly separating the two formations in the Buckner field. As yet there is no evidence of thickening or thinning in the basal part of the Buckner formation to bear out this theory. On the other hand, there is evidence that in the Magnolia field the Buckner formation thins on structure by the loss of section at the top.

2. "The Buckner formation is represented at Schuler by the Jones sand." Evidence for this theory lies in the presence of a thin, hard, dolomitic bed of sandstone between the anhydrite and limestone in wells drilled in Sec. 8, T. 18 S., R. 12 W., and in Sec. 5, T. 18 S., R. 14 W., in eastern Union County. It should be noted that in these cases the sand was apparently conformable with both the

overlying anhydrite and the underlying limestone. At Schuler there is evidence of an unconformity between the sandstone and the limestone.

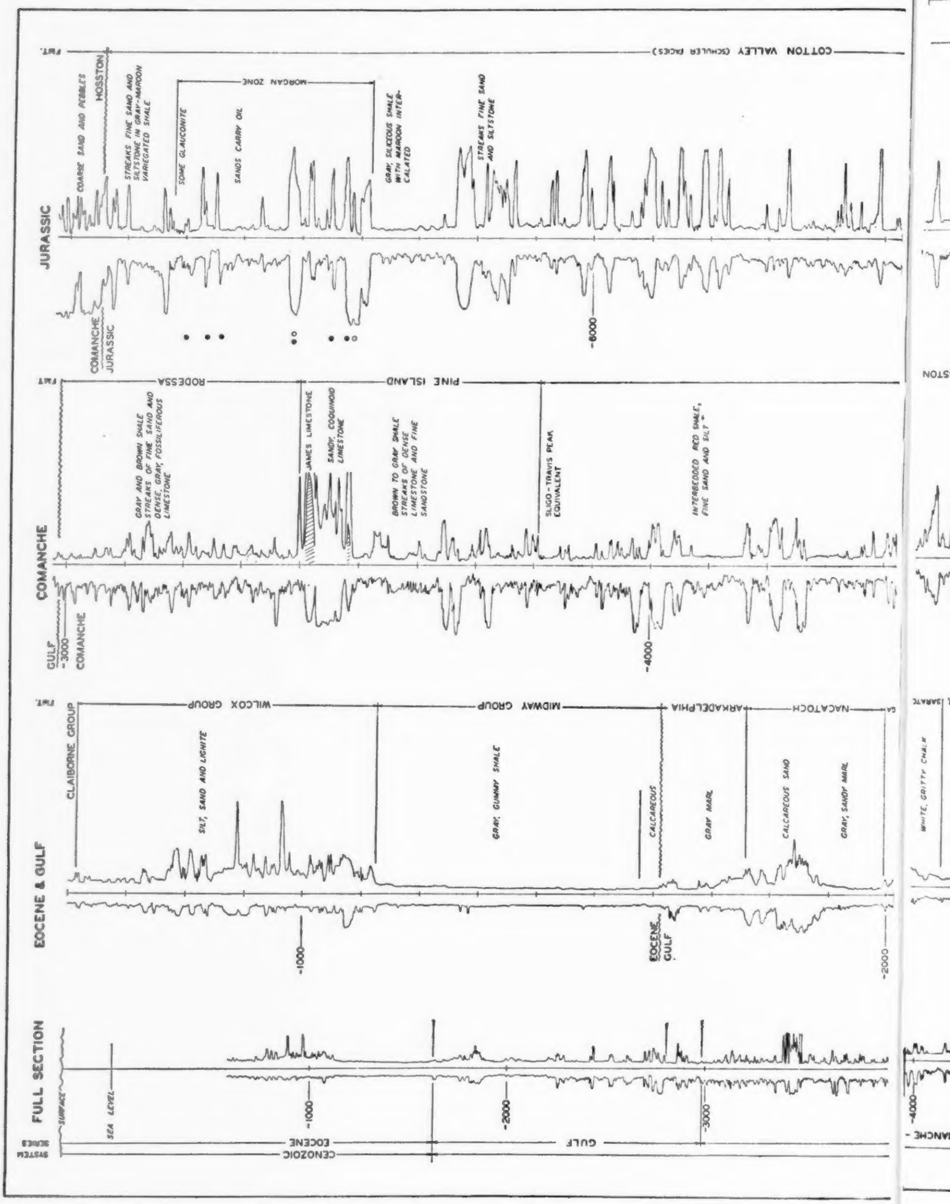
The more detailed stratigraphy of this area can best be shown by a typical log constructed from electrical records and the examination of well cuttings and cores. The log of the Phillips Petroleum Company's Marcus Justiss No. 3, the deepest well in the field, follows.

LOG OF PHILLIPS PETROLEUM COMPANY MARCUS JUSTISS NO. 3

Center Lot 6, in NW. ¼ Sec. 18, T. 18 S., R. 17 W.
Elevation 248 feet

	Depth in feet
EOCENE SERIES	
CLAIBORNE GROUP	
Coarse loose sand with streaks of dark finely micaceous shale	0–240
Interbedded gray shale, silt, and unsorted sand with streaks of lignite and much brown crypto-crystalline siderite	500
Lignitic gray sandy silt and shale	640
Interbedded gray silty shale and lignite	700
Gray to brownish gray gummy, slightly calcareous shale with nodular glauconitic brown crypto-crystalline siderite	863
WILCOX GROUP	
Interbedded fine gray silt, sand and silty shale, with plentiful streaks of lignite between 970 and 1,375. Streaks of fine calcareous sand and finely sandy limestone between 1,050 and 1,250	1,375
MIDWAY GROUP	
Finely micaceous gray gummy shale	1,830
Gray gummy calcareous shale	1,863
GULF SERIES	
ARKADELPHIA MARL	
Gray marl with streaks of soft white chalk within top 30 feet and some gritty marl within middle 20 feet	2,006
NACATOCH FORMATION	
Fine to medium-grained calcareous white sand with argillaceous streaks in upper half. Lower half borders on sandy limestone	2,137
Very finely gritty gray marl	2,243
SARATOGA CHALK	
Hard white chalk with a few scattered grains of very fine sand and glauconite	2,325
MARLBROOK MARL	
Light gray marl	2,448
ANNONA CHALK	
Hard white chalk with a few grains of very fine sand and glauconite	2,468
OZAN FORMATION	
Very finely gritty gray marl	2,504
Fine angular-grained calcareous porous slightly glauconitic sand (Meakin)	2,520
Gray shale	2,533
Sandy glauconitic gray shale	2,553
Dark gray shale	2,602
Thin-bedded gray shale and fine calcareous glauconitic sand with disseminated fine quartz pebbles	2,610
Gray shale with streaks of fine porous glauconitic sand	2,671
Fine tight glauconitic calcareous sand (Graves ?)	2,692
Gray shale with thin streaks of fine glauconitic sand	2,771
Fine glauconitic, micaceous, slightly porous and lignitic sand (Buckrange ?)	2,790
BROWNSTOWN FORMATION (Restricted)	
Gray, somewhat finely sandy shale	2,843
Fine, tight glauconitic calcareous sand with argillaceous streaks	2,890
Gray shale	2,915
TOKIO FORMATION	
Gray to brown shale with laminations of fine lignitic sand with some white volcanic ash	2,945
Fine- to medium-grained angular porous sand with white ash matrix, considerable lignite	

and abundance of brown siderite near base. There are argillaceous streaks, especially near top. Basal 5–10 feet contains abundance of fine quartz pebbles and some pink chert pebbles	3,039
EAGLE FORD FORMATION (6)	
Gray friable finely gritty and glauconitic shale	3,106
Medium- to fine-grained ash-bearing porous sand with some brown siderite	3,132
Variegated red, purple and gray shale with streaks of chloritic, ashy sand and green bentonitic clay	3,233
COMANCHE SERIES	
TRINITY GROUP	
RODESSA FORMATION	
Red to dull brown shale with a few thin streaks of very fine white sand. Bottom 40 feet has abundant fine calcareous white sand	3,410
Red shale with streaks of gray fossiliferous sandy limestone and of fine porous white sand. Two 10-foot limestone streaks at 3,410 and 3,470 are probably equivalent to lower or variegated Gloyd limestone zone of Rodessa area	3,646
PINE ISLAND FORMATION	
Dense limestone at top, grading to porous coquina and through sandy coquina to calcareous sand at base (James limestone)	3,737
Fine dull brownish gray shale with a few thin streaks of limestone	3,775
Light gray finely crystalline fossiliferous limestone	3,798
Dull brownish gray shale with thin streak of very fine sand at top	3,852
White to gray fossiliferous dense limestone with traces of fine grit and glauconite grains and some yellow limonitic stains	3,856
Dull brownish gray shale with streaks of fine angular white porous sand and dense gray limestone. Interbedded sand and limestone in last 20 feet contains slight oil stain	4,063
HOSSTON FORMATION (Includes Sligo and Travis Peak formations ?)	
Red shale with frequent streaks of fine white silt and fine porous white sand	4,697
Interbedded red shale and fine angular porous white sand and silt, with pale yellow dolomite nodules in sands and silts (Champagnolle zone)	4,875
Same as above, except sands vary up to medium-grained and contain here and there grains of green chlorite and black chert	5,215
Medium-grained sand with streaks of red shale. Sand contains disseminated small pebbles of quartz and vari-colored chert, particularly abundant near base	5,407
JURASSIC SERIES (?)	
COTTON VALLEY FORMATION	
Interbedded fine sands and silts with variegated talc-like olive-gray and maroon shales	5,529
Brownish gray slightly glauconitic shale with a few brachiopod fragments (top of Morgan zone)	5,542
Fine silt with streaks of fine tight sand, with oil stain	5,563
Variegated gray and maroon shale	5,581
Fine porous oil-bearing sand	5,589
Gray siliceous shale	5,605
Fine porous oil-bearing sand	5,609
Variegated shale with streaks of siltstone	5,728
Fine angular sand with oil stain in upper half	5,747
Variegated shale	5,763
Fine tight silty sand	5,770
Variegated shale with streaks of fine tight sand	5,824
Medium to coarse-grained angular sand with disseminated grains of black chert. Oil stain in top 6 feet	5,865
Variegated shale with some streaks of fine tight sand and silt	6,013
Interbedded streaks of variegated shale and medium- to fine-grained sands	6,483
Red and variegated shales with streaks of fine- to medium-grained sand. A few streaks of fine red argillaceous sand below 6,900 feet. Sands are lignitic in many places	7,205
Fine-grained red argillaceous sand interbedded with red shale and 10- to 30-foot thick beds of medium-grained black chert-bearing white sand. Some streaks of variegated shale	7,477
Gray siliceous shale with streaks of tight hard fine siltstone showing spotted stains of oil	7,504
Fine- to medium-grained oil-bearing sand with a few tight silty streaks (Jones sand)	7,570
Fine tight silty sand with oil stain in porous spots, and streaks of gray shale and siltstone. Disseminated gravel pebbles of chert and quartz at base of this section	7,604



JURASSIC
COTTON VALLEY (SCHULER FACIES)
HOSSTON
COARSE SAND AND PEBBLES
STREAKS FINE SAND AND SILTSTONE IN GRAY-MAROON VARIEGATED SHALE
MORGAN ZONE
SOME GLAUCONITE
SANDS CARRY OIL
GRAY, SILICEOUS SHALE WITH MAROON INTERCALATED
STREAKS FINE SAND AND SILTSTONE
COMANCHE
JURASSIC
-6000
COMANCHE
RODESSA
PINE ISLAND
GRAY AND BROWN SHALE STREAKS OF FINE SAND AND DENSE, GRAY, FOSSILIFEROUS LIMESTONE
JAMES LIMESTONE
SANDY, COQUINOID LIMESTONE
BROWN TO GRAY SHALE STREAKS OF DENSE LIMESTONE AND FINE SANDSTONE
SLIGO-TRAVIS PEAK EQUIVALENT
INTERBEDDED RED SHALE, FINE SAND AND SILT
GULF
-3000
COMANCHE
-4000
EOCENE & GULF
CLAIBORNE GROUP
WILCOX GROUP
MIDWAY GROUP
ARKADELPHIA
NACATOCH
SILT, SAND AND LIGNITE
GRAY, GUMMY SHALE
CALCAREOUS
GRAY MARL
CALCAREOUS SAND
GRAY, SANDY MARL
WHITE, GRITTY CHALK
-1000
EOCENE
GULF
-2000
FULL SECTION
SURFACE
SEA LEVEL
-1000
-2000
-3000
-4000
SYSTEM
SERIES
EOCENE
GULF
CENOZOIC

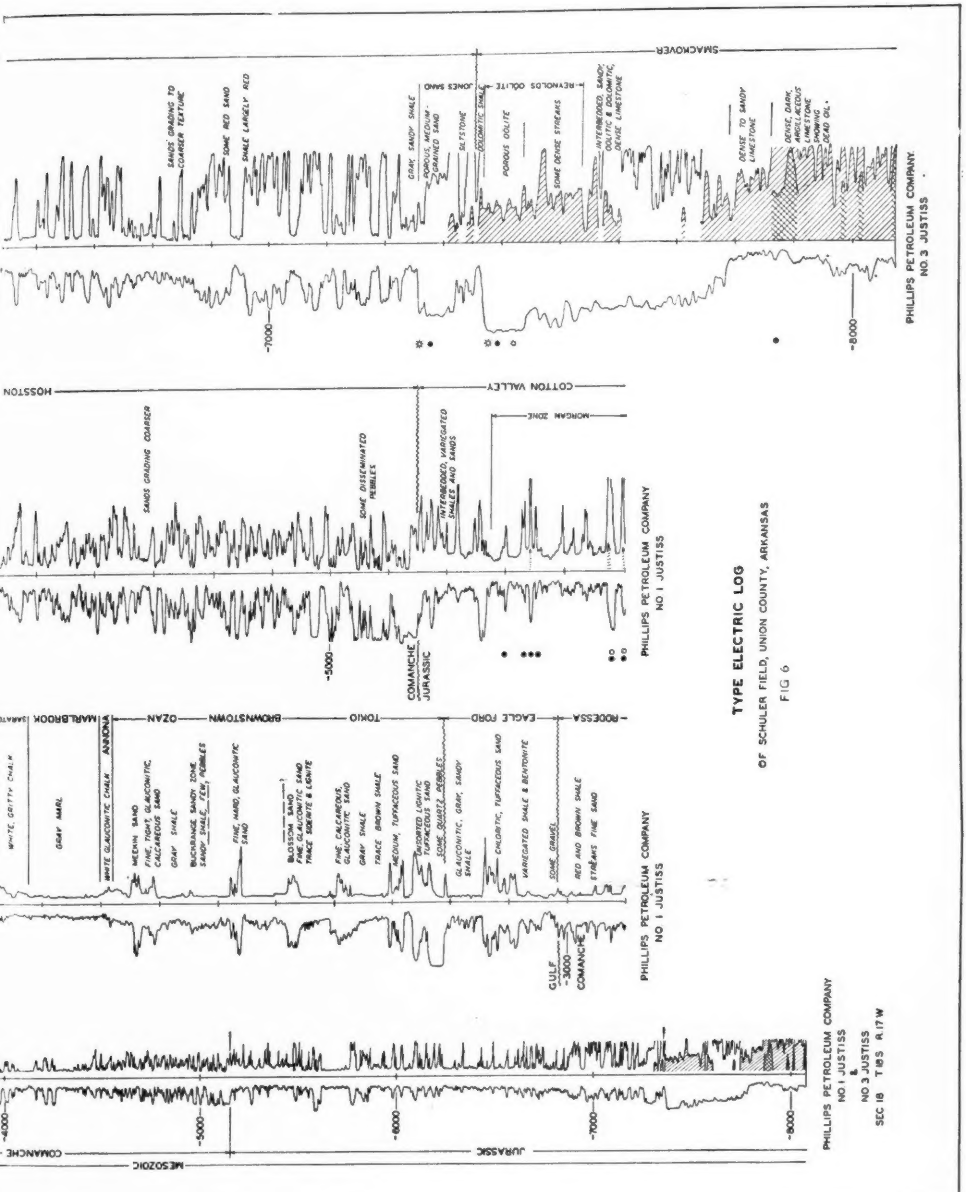
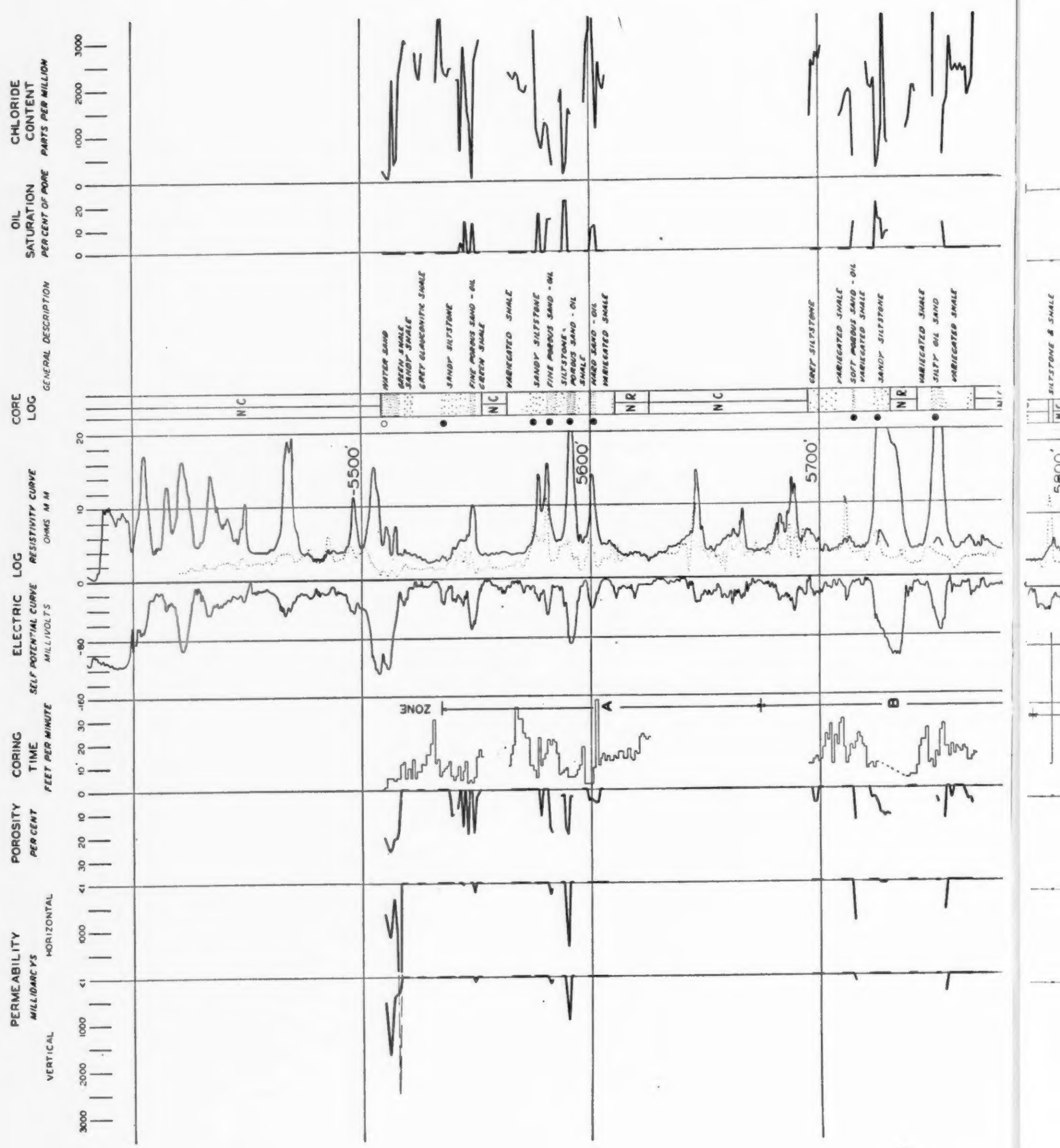


FIG. 6.—Typical electric log, Schuler field.


CHLORIDE CONTENT
PARTS PER MILLION
OIL SATURATION
PER CENT OF PORE
CORE LOG
GENERAL DESCRIPTION
ELECTRIC LOG
RESISTIVITY CURVE
OHMS M M
SELF POTENTIAL CURVE
MILLIVOLTS
CORING TIME
FEET PER MINUTE
POROSITY
PER CENT
PERMEABILITY
MILLIDARCYS
VERTICAL
HORIZONTAL
-5500'
5600'
5700'
ZONE
A
B

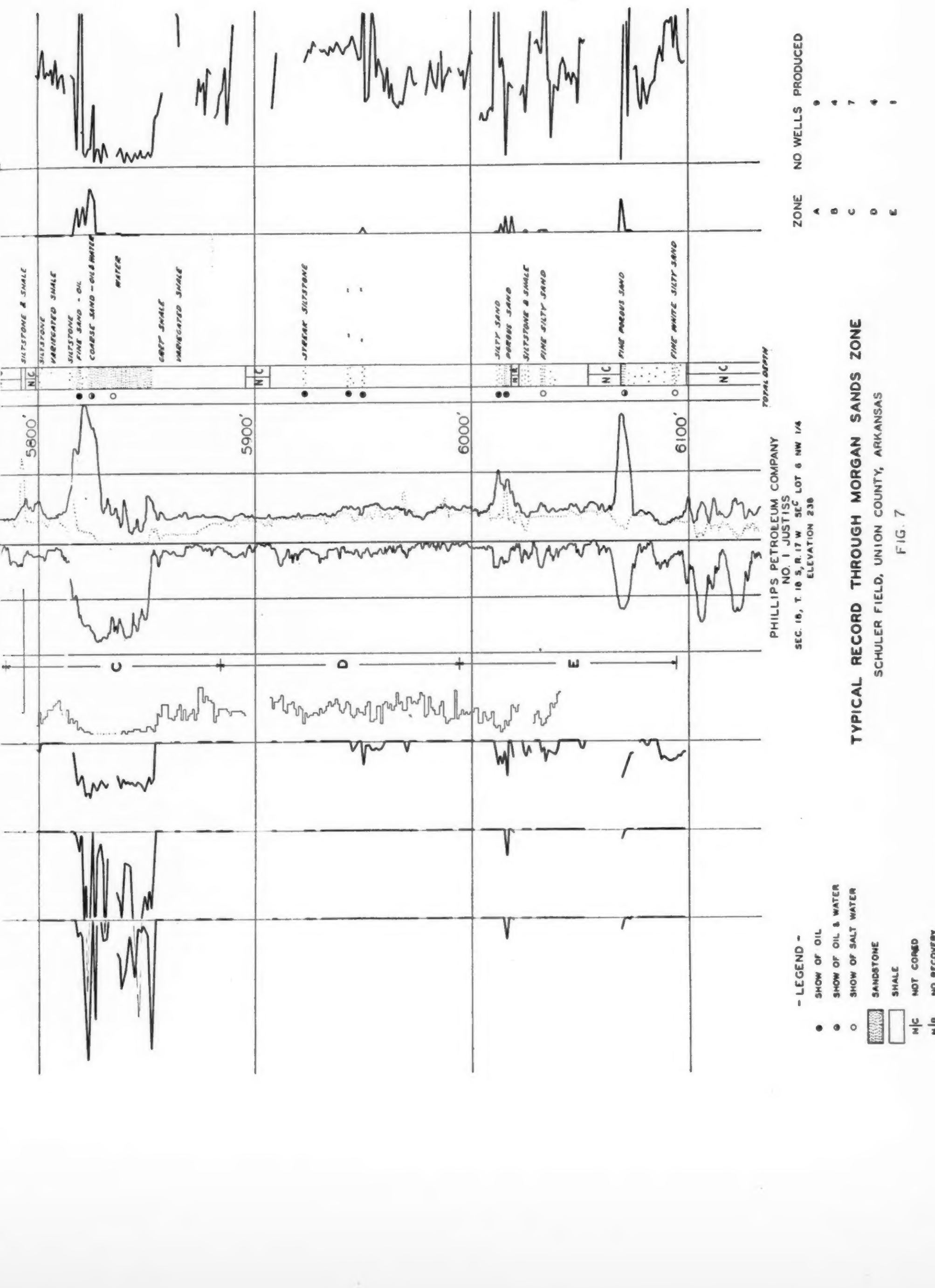


FIG. 7.—Typical record through Morgan Sands zone comparing all pertinent physical data, Schuler field.

SMACKOVER FORMATION

Hard dense brownish gray limestone	7,605
Hard grayish green calcareous shale	7,609
Hard dense dark gray limestone with oölitic structure faintly apparent	7,617
Porous oölitic limestone, containing oil down to 7,667 (Reynolds oölite)	7,687
Slightly porous oölitic to pisolitic gray limestone	7,708
Hard dense brownish gray slightly gritty limestone with faintly oölitic structure here and there	7,747
Porous oölitic, slightly pisolitic limestone with stylolitic structure	7,756
Brown slightly sandy dense limestone	7,768
Dense brown limestone with oölitic slightly porous streaks	7,778
Dense brownish gray limestone with faintly apparent oölitic structure, and here and there a slightly porous streak	7,890
Buff-brown slightly oölitic dense limestone with gray to white oölitic chert scattered throughout	7,940
Buff to brown dense limestone with disseminated fine rhombic dolomite crystals	7,997
Crypto-crystalline brownish gray dense limestone with some disseminated dolomite rhombs in basal half	8,028
Crypto-crystalline dense brown limestone with disseminated grains of fine sand	8,111
Dense brown crypto-crystalline fractured limestone with very thin streaks or partings of black shale and more commonly streaks of black argillaceous limestone. Fractures contain dark oil stains down to 8,164, and show some gas between 8,190 and 8,225 (Total depth)	8,328

Figure 6 is a typical electric log composed from the log of the deepest well in the field and that of a near-by shallow producer. Most of the formational divisions stand out well on the electric log. Exceptions include the Gulf-Comanche and Pine Island-Hosston contacts, which can be more easily determined with the aid of well cuttings. The Hosston-Cotton Valley contact is locally recognizable by the sudden decrease in the amount of sandstone. A more consistent characteristic is the concurrent sudden increase in the electrical resistance of the sandstone.

RESERVOIR ROCKS

Morgan Sands zone.—The shallowest production in the Schuler field is from a series of lenticular sandstones within a 500-foot section, lying immediately under a 13-foot bed of brownish gray glauconitic slightly fossiliferous shale, approximately 140 feet below the top of the Cotton Valley formation. Figure 7 shows a typical record through the Morgan zone, with data from the core analyses plotted beside the coring-time graph, electric curves, and plotted core record for comparison. No showings of oil have been recorded within the Cotton Valley formation above this Morgan zone. Showings of oil have been reported in sands below this zone, but only one above the Jones sand has been proved productive to date.

Except for the presence of oil in commercial quantities, and the presence of the 13-foot bed of glauconitic shale, the top of which contains a few small unidentified pelecypods, the Morgan zone is similar in character to the Cotton Valley formation, both above and below. The section is apparently of non-marine or shallow-water deposition, as indicated by the absence of fossils and the occurrence of red color. The section is composed of variegated light gray and maroon siliceous shales, grading laterally and vertically to siltstones and sandstones.

The sandstones vary in texture from very fine through coarse. The grains are

predominantly quartz with a noticeable amount of black chert in the coarser-grained beds. The porosity of the sandstones varies, ranging up to 26 per cent, with an average porosity of about 16 per cent. Permeabilities vary up to 4,500 millidarcys with an average between 500 and 1,000 millidarcys. Zones indicated in Figure 7 are arbitrarily selected to indicate the grouping of production.

Figure 8 is a northwest-southeast detailed cross section through the Morgan Sands zone, constructed and interpreted from electric logs, core and cuttings records, and time graphs. An attempt has been made to indicate the relative porosity and permeability of the sandstones by the size and spacing of the dots. They do not represent actual values. Oil-water contacts have been indicated where known. Although the data from these wells may be interpreted by various other pictures, any possible interpretation would show a similar series of disconnected lenticular sand bodies, grading laterally and vertically through siltstone to shale.

The presence of grains of black novaculite, similar to the Devonian (?) novaculite of the Ouachita Mountain area, is an indication that this mountain area was a source for the material deposited during Cotton Valley time. Imlay (7, p. 27) presents evidence that the Cotton Valley formation is probably latest Jurassic, possibly earliest Comanche. The writers are of the opinion that in its downdip facies it may bridge what is elsewhere the hiatus between Comanche and Jurassic.

Leona sand.—The Leona sand, at the depth of 6,900 feet, producing in three wells, is known only from well cuttings and electric logs. It is similar to the sands previously described, being of medium to fine texture. There is no information on porosities or permeabilities.

Jones sand.—Figure 9 is a typical record of the Jones sand and Smackover limestone section, comparing the electrical curves with the core log and cutting time, and with the various core-analysis graphs. The Jones sand is the main producing zone in the Schuler field. The angular sand grains vary in texture from very fine to medium, and are principally quartz. The black novaculite grains, abundant in many of the overlying sands of the Cotton Valley formation, are not noticeable in this sand. The porosity and permeability of the sandstone vary throughout the field, depending largely on the texture and the amount of silt.

In general, the sandstone grades finer, more silty, and less permeable and porous toward the base, and laterally toward the edges of the field, particularly toward the southeast part of the field. The porosity of the sand ranges from 0 to 35 per cent, with an average of approximately 20.2 per cent. The horizontal permeability ranges upward to 4,000 millidarcys with an average near 395 millidarcys, taken from an analysis of 1,500 samples from 41 key wells. The vertical permeability is somewhat less.

Figure 10 shows cross sections through the Jones sand. The coarseness of the dots in the sandstone sections indicates the relative permeability and porosity, but can not be interpreted in exact figures. These pictures illustrate the general

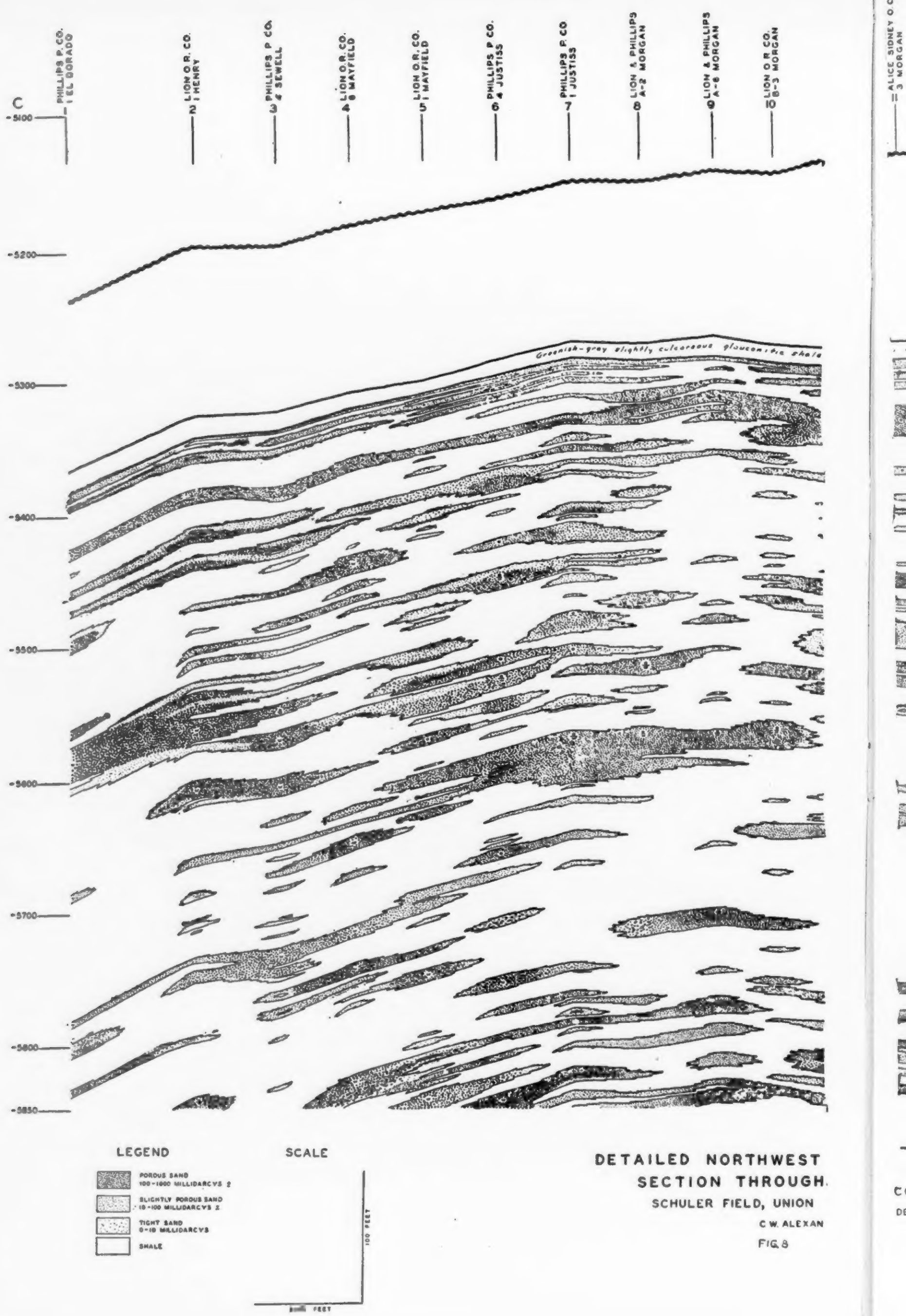
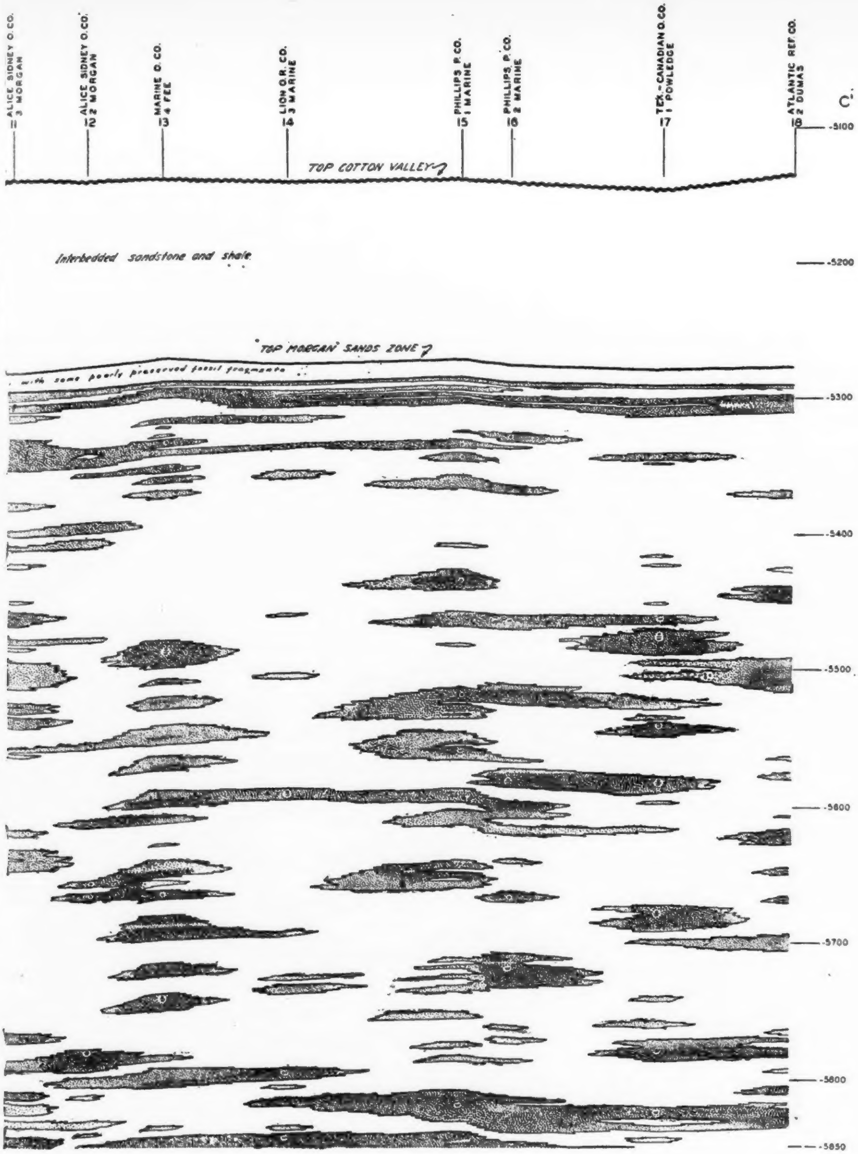
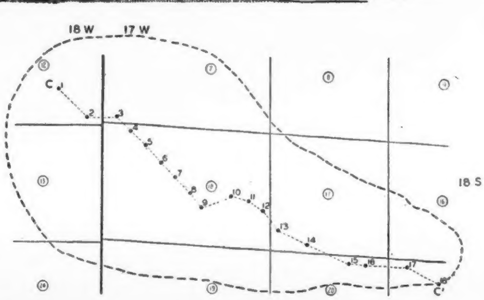


FIG. 8.—Northwest-southeast detailed cross section



-SOUTHEAST CROSS
MORGAN ZONE
COUNTY, ARKANSAS
DER



through Morgan Sands zone, Schuler field.

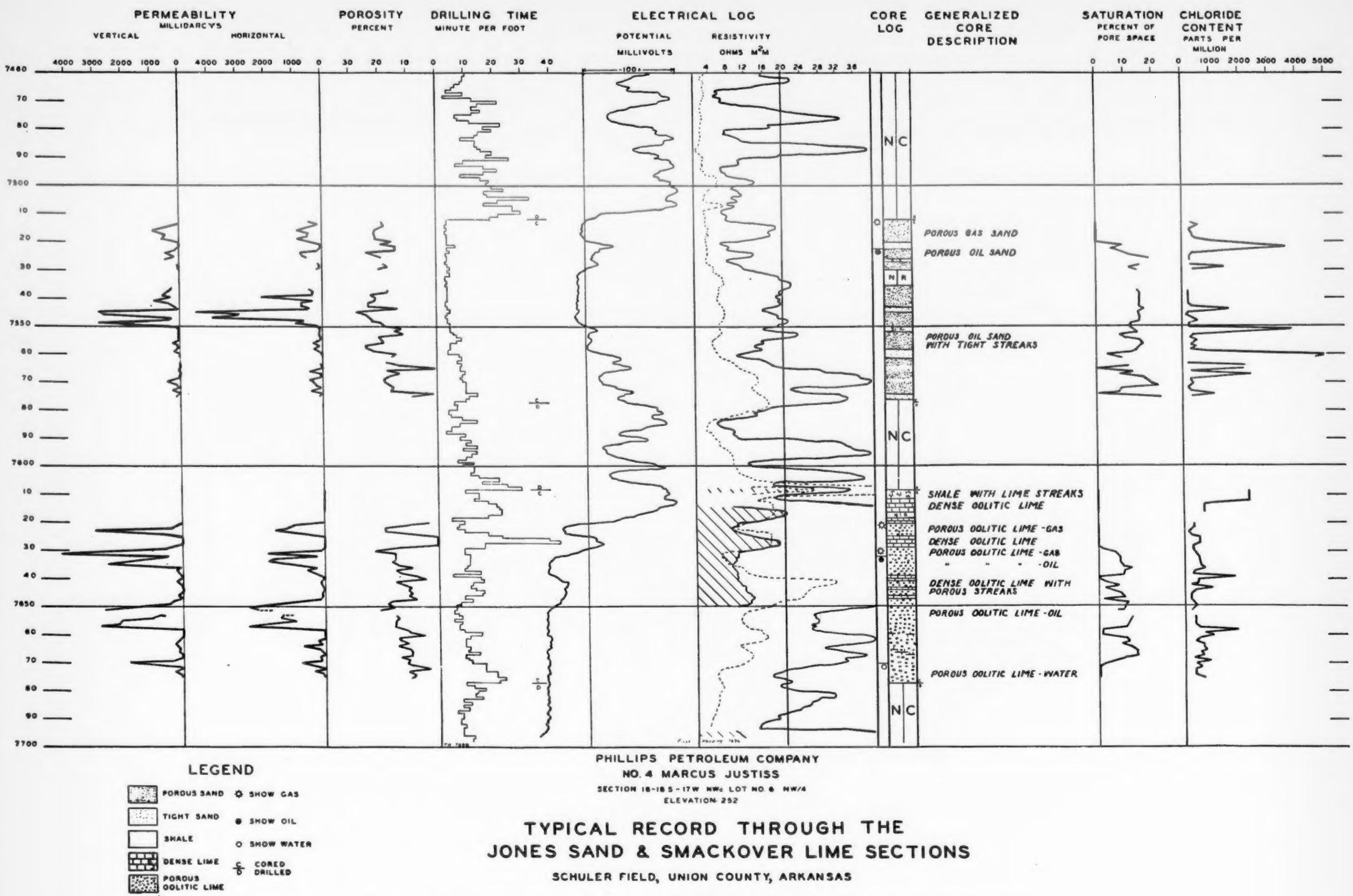


Fig. 9.—Typical record through Jones sand and Smackover limestone sections, Schuler field.

thinning and tightening of the sandstone off structure. The appearance of residue oil or asphalt around the flanks of the field is shown. As previously pointed out, the Jones sand is probably basal Cotton Valley in age. However, there is a possibility that it is the Buckner equivalent.

Reynolds oölite.—The Reynolds oölite zone of porosity in the upper part of the Smackover limestone formation is the lowest producing zone in this field. A typical section is shown with the overlying Jones sand in Figure 9. A more general picture of this zone may be obtained from Figure 10.

The "cap rock" which is the top of the Smackover formation, and which immediately overlies the porous zone, varies in thickness from 2 or 3 feet in the southeast part of the field to approximately 15 feet in the northwest sector. It consists of hard, dense limestone with streaks of calcareous shale in the upper part, where it is thickest. The color of the limestone varies from tan to gray. The texture is crypto-crystalline; however, a faint vestige of oölitic structure can be recognized.

The underlying porous oölite consists of typical concentrically grown spherical oölites, ranging in size from very fine to coarse and with a few pisolites the size of a small pea. Throughout most of the zone the oölites are only very loosely cemented, resulting in high porosities and permeabilities. The porosity ranges to more than 23 per cent, with an average of 16.7 per cent, only 83 per cent as porous as the Jones sand. The horizontal permeability ranges to more than 15,000 millidarcys with an average of 1,176 millidarcys, as determined from a study of the analyses of 469 samples run on 15 wells. The oölite differs from the sand in that the vertical permeability is very nearly as large as the horizontal.

The Reynolds oölitic porous zone is present in a band about 25 miles wide, which arches through southernmost Arkansas southwestward to a known occurrence in Limestone County in eastern Texas. Its extent toward the southeast has not been determined. Imlay (7, p. 20) pictures the Reynolds zone as a reef, comparing it to the fringing reefs of the Jurassic of England. He places the age as Middle or Upper Jurassic (7, pp. 19–20), presenting the paleontologic evidence. This oölitic zone is free from the secondary dolomitization which is prevalent in this formation adjacent to the Arkansas fault zone.

STRUCTURE

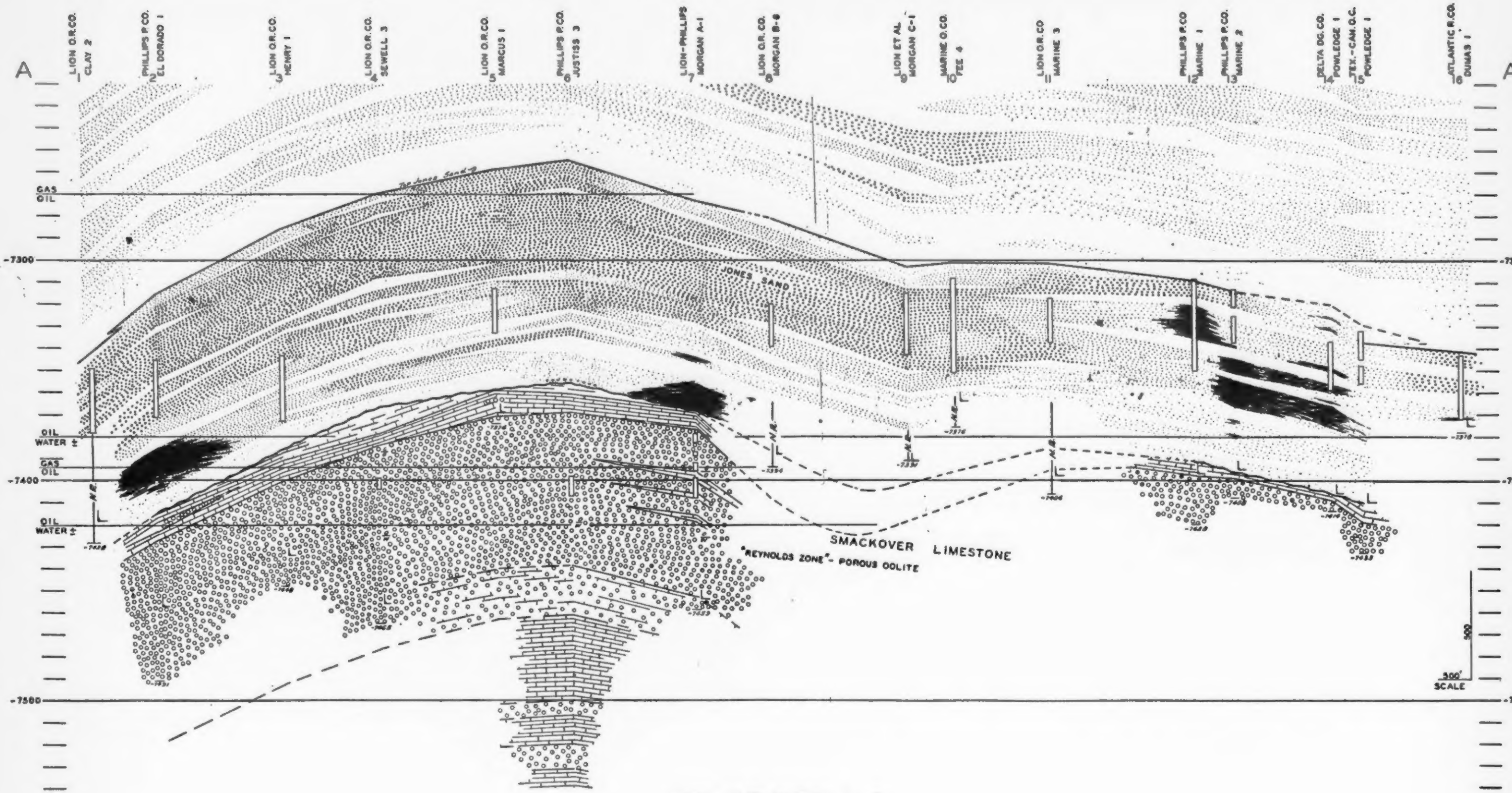
SURFACE STRUCTURE

As far as the writers can determine, the specific structure of the surface beds is not recognizable in the Schuler area.

SUBSURFACE STRUCTURE

Spooner, in 1935, commented on the "structural trend" which "begins in the Stephens field and extends southeastward into the northwest corner of T. 19 S., R. 16 W." His structural interpretation on the top of the Nacatoch sand shows a broad nose centering over T. 18 S., R. 17 W., the vicinity of Schuler, plunging

Fig. 10, upper



WEST - EAST SECTION A - A'

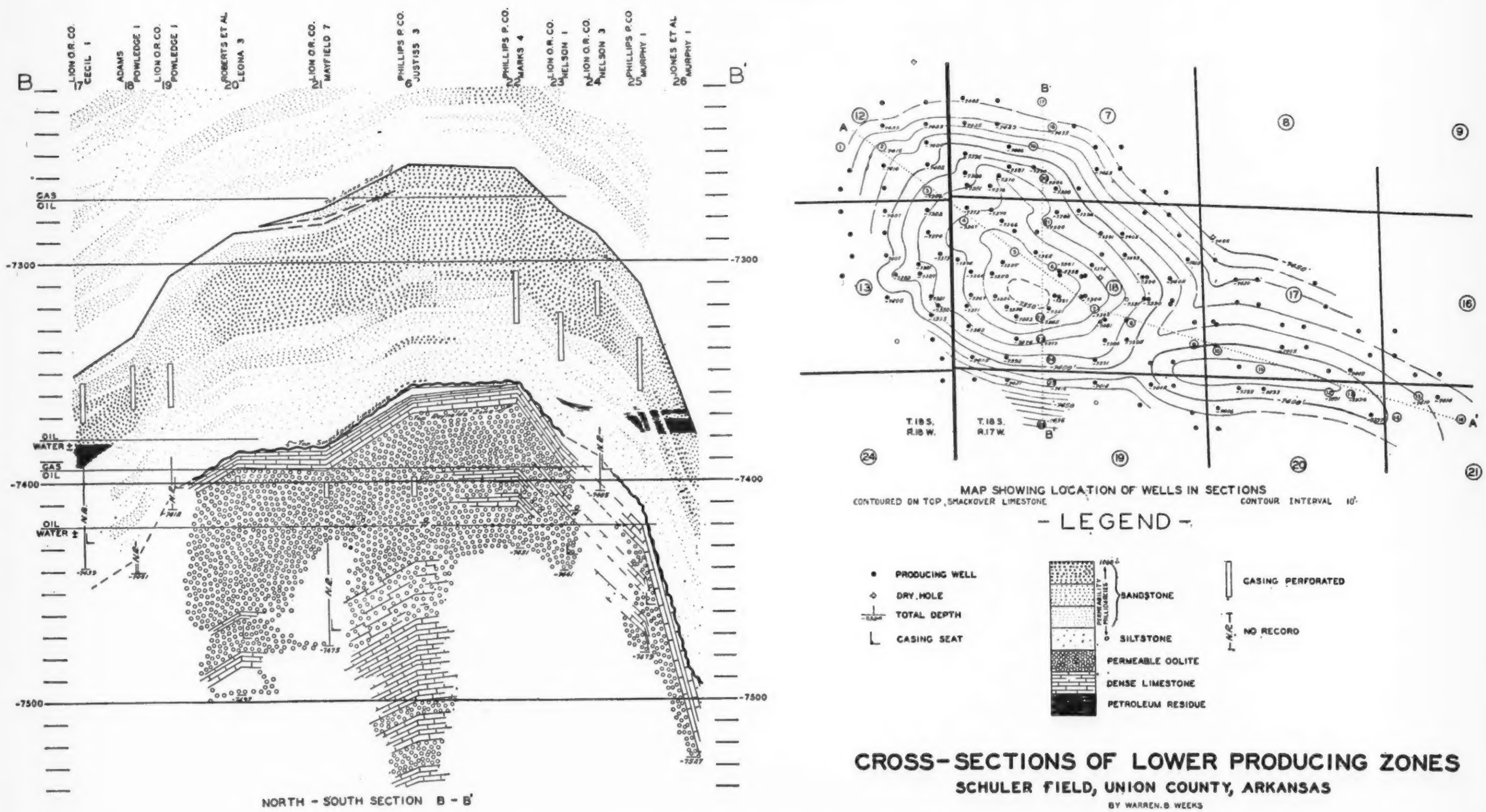


FIG. 10.—Cross sections of lower producing zones. Schuler field.

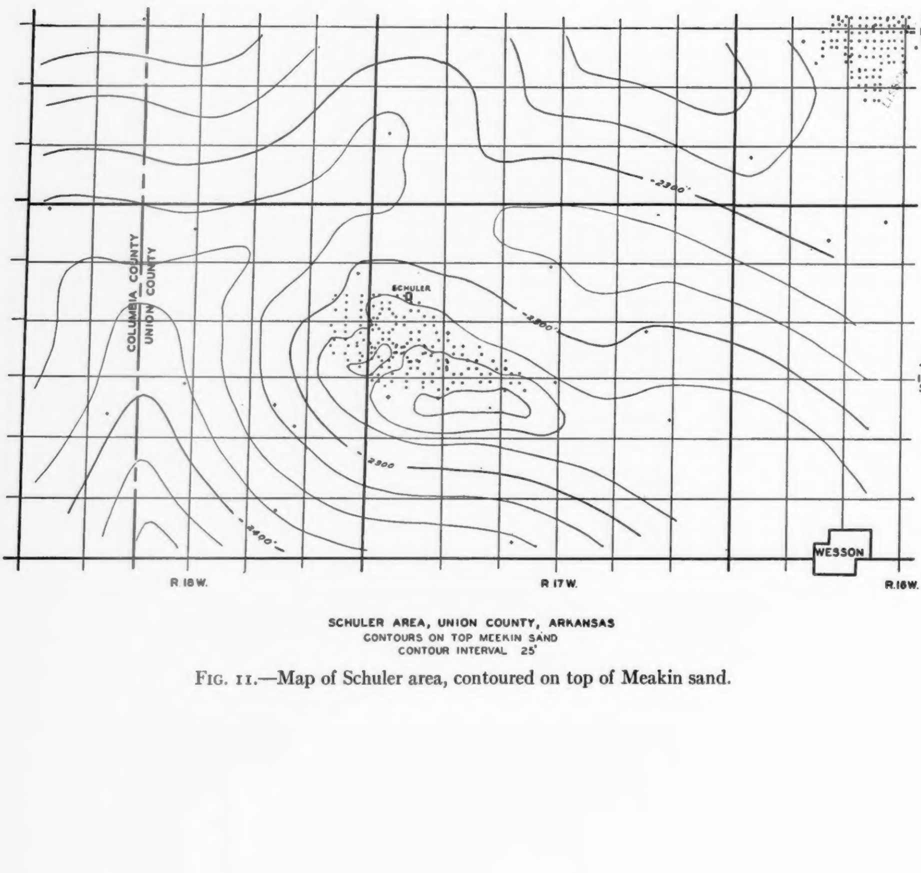


FIG. 11.—Map of Schuler area, contoured on top of Meakin sand.

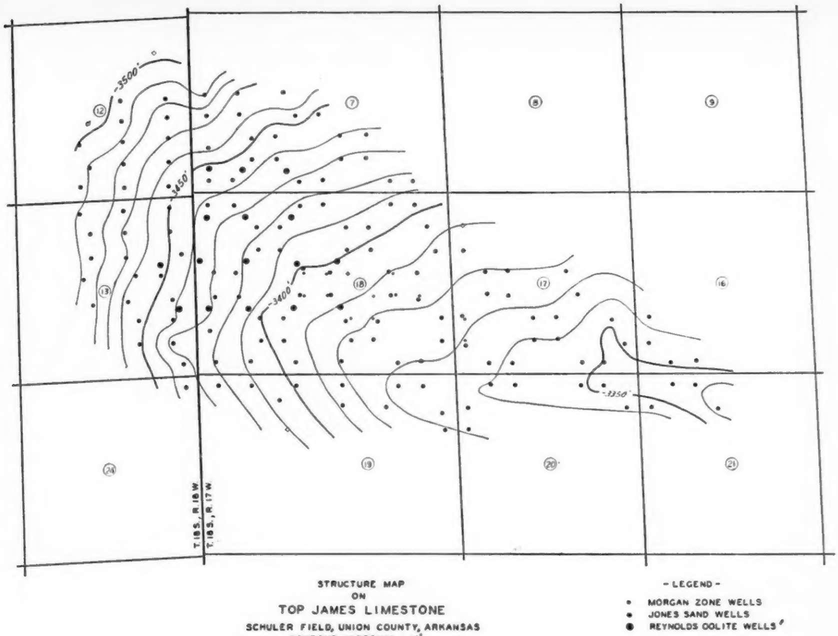


FIG. 12.—Structure map contoured on top of James limestone, Schuler field.

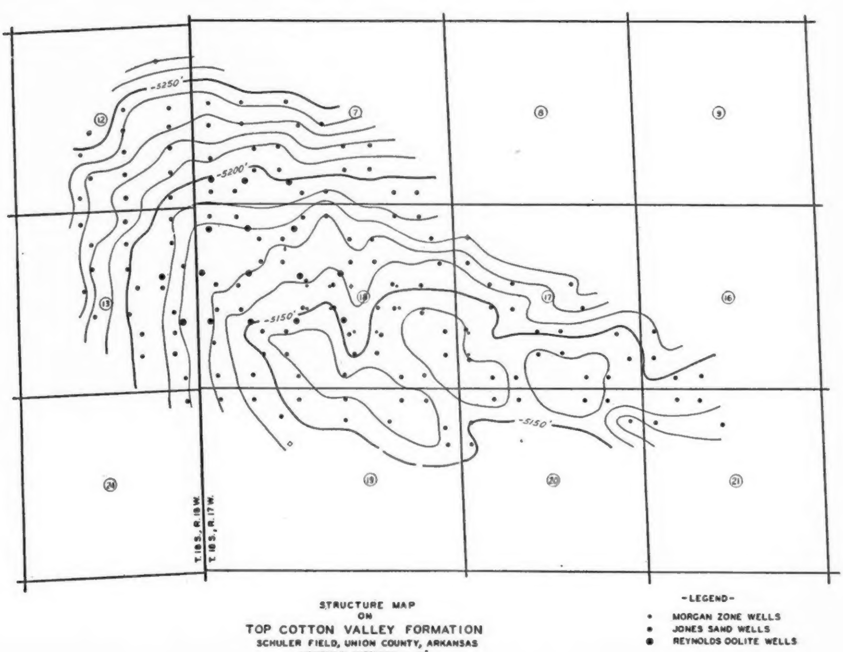


FIG. 13.—Structure map contoured on top of Cotton Valley formation, Schuler field.

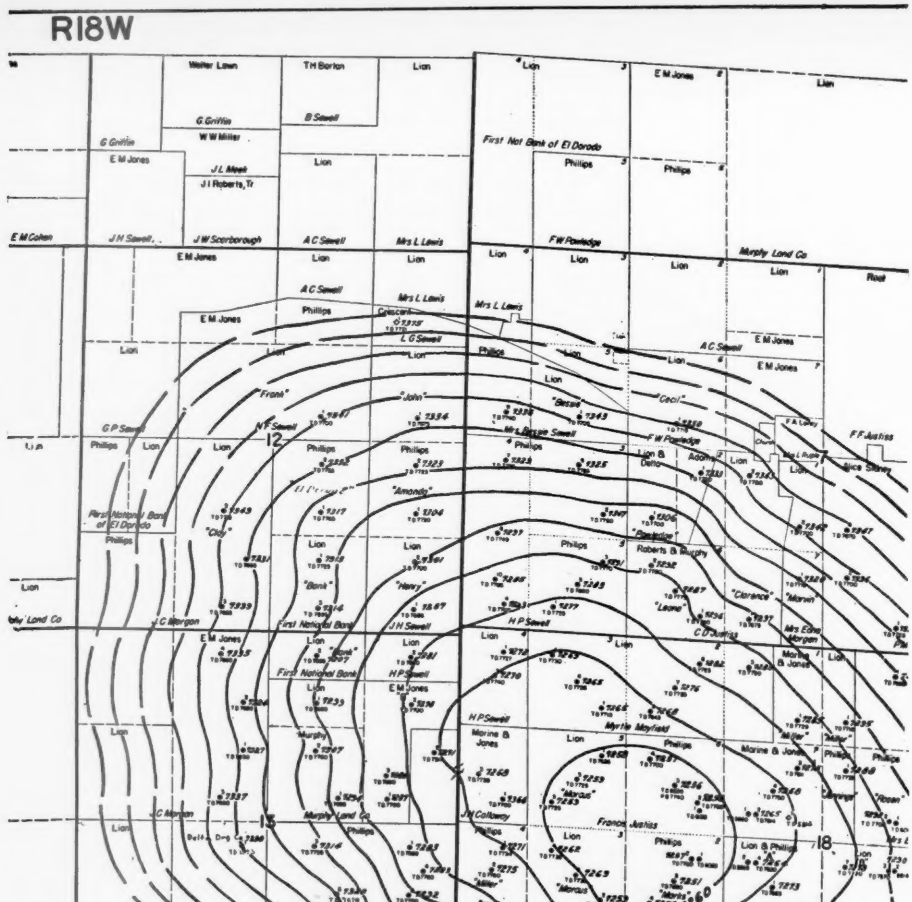
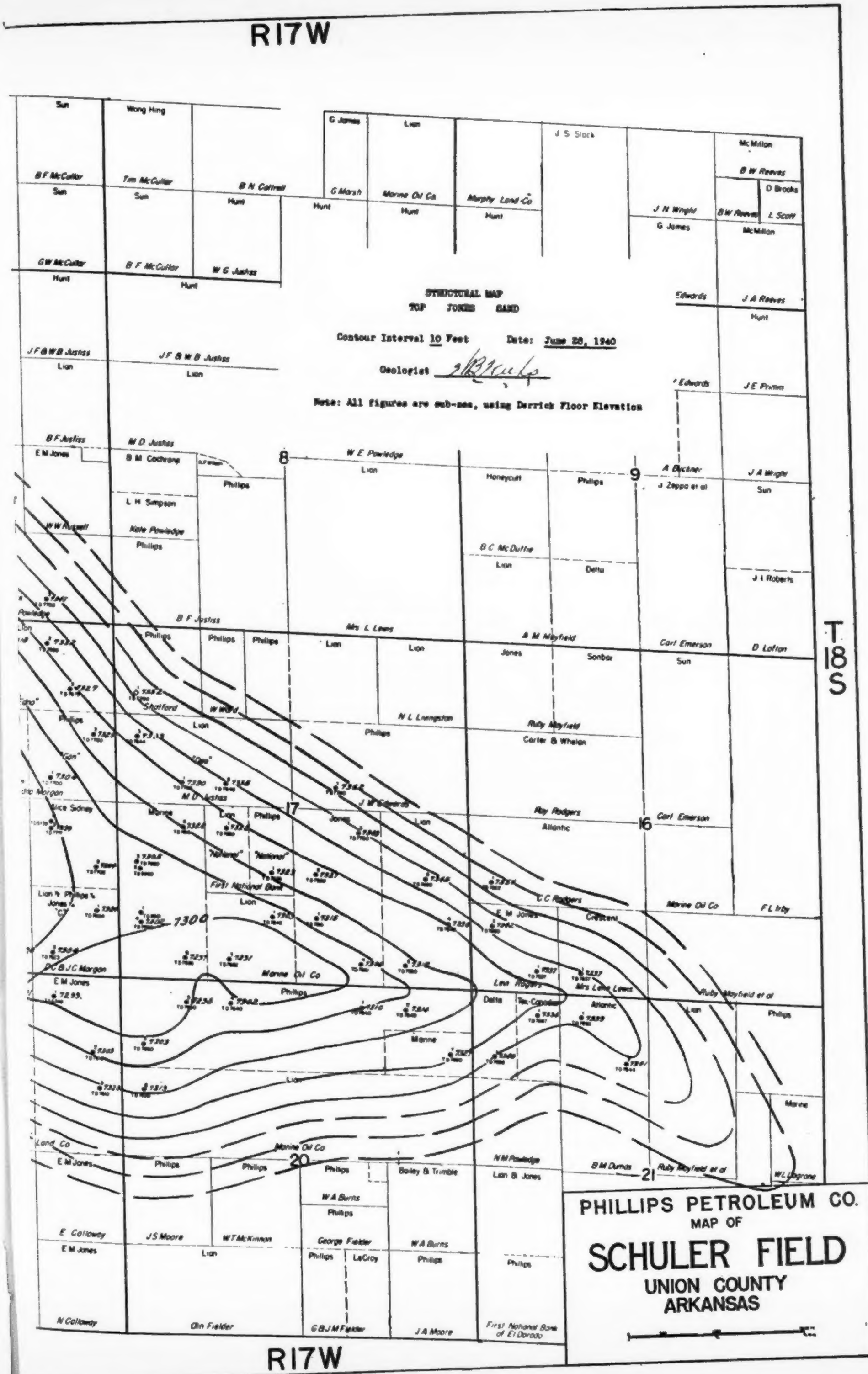


FIG. 14.—Structure map contoured



on top of Jones sand, Schuler field.

toward the southeast (9, Fig. 93). Figure 4 (9, Pl. XX) shows his structural interpretation with contours on top of the Meakin sand, the first sand below the Annona chalk. This map shows the southeastward-plunging nose just northeast of Schuler.

Figure 11 shows the present known structure in the Gulf series, as contoured on top of the Meakin sand. Structural closure is not definitely proved by the field wells which show north dip across the field, but may be inferred to lie just

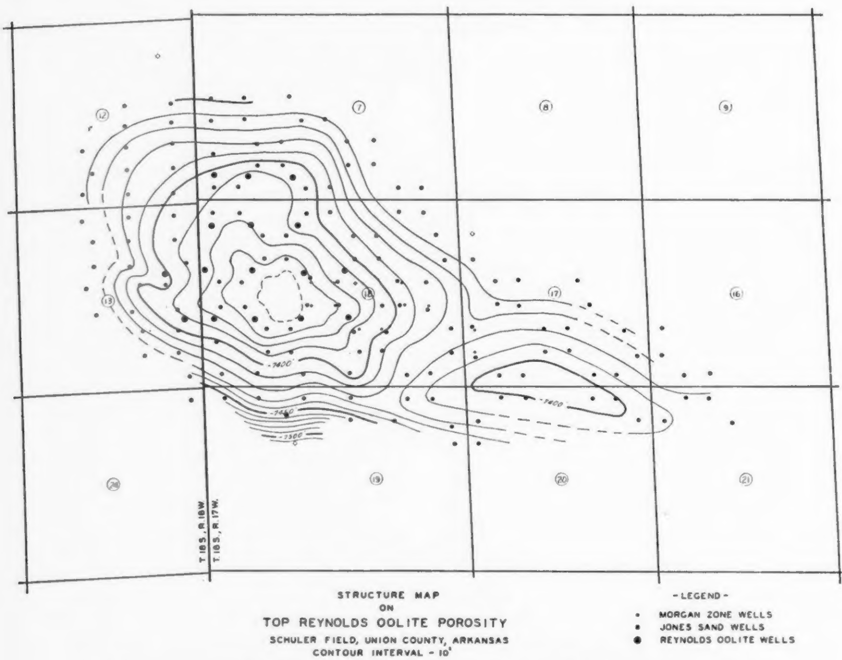


FIG. 15.—Structure map contoured on top of Reynolds oölite porosity, Schuler field.

south of the field since the regular dip off of the general structural trend is southwest. On the other hand, any possible structural closure in the Comanche beds must lie east of the field proper, since the wells in the field show only west dip when contoured on top of the James limestone (Fig. 12).

With greater depth, the top of the structure is farther west, as shown by Figure 13, contoured on the top of the Cotton Valley formation. Figure 14, showing structure contoured on the top of the Jones sand producing zone near the base of the Cotton Valley formation, places the structurally high point still farther north and west. This conforms to the structure as contoured on the top of the underlying Smackover formation (Fig. 10) and the producing Reynolds

oölite zone (Fig. 15). The top of the Jones sand is the shallowest mappable horizon which actually shows closure. On it there is a minimum structural closure of 90 feet, with more than 135 feet indicated. Due to shifting or tilting, resulting in the lack of critical control, the structural closure in the shallower beds can only be inferred. Indications are that the structure in the Gulf series beds is somewhat broader with less than half as much closure as that of the Jones sand.

GEOLOGIC HISTORY

Imlay (7, pp. 54–57), discusses the general geologic history of southern Arkansas. The history of this area is mentioned here only insofar as it is necessary to explain the stratigraphy and structure in the Schuler field. The complex history of the area is indicated by the non-uniformity of the structural shifting at Schuler.

Imlay (7, Pl. XIII) indicates that Schuler lies in the south part of Buckner deposition. Certainly there is no Buckner present at that locality. As pointed out elsewhere in this paper, it can not definitely be determined whether it is absent due to erosion, non-deposition, or is represented by the Jones sand section. Since the area is so near the southern limits of Buckner occurrence, we should expect some remaining feather-out streaks of anhydrite. Their absence indicates to the writers that a possibly thin Buckner section may have been eroded before the deposition of basal Cotton Valley. This theory is borne out by the more definite erosional absence of Buckner in the area of northeastern Union County; the thinning of this formation over the top of structures where it is present and apparently conformable with the underlying Smackover formation; the presence of Buckner in a well drilled farther south, in the old Haynesville field; and the actual erosion into the Smackover limestone at Schuler, as evidenced by the varying thickness of the dense limestone at the top, the absence of the overlying shaly zone in part, the absence of the dense limestone cap over the top of the southeastern "high," and the abrupt lithologic break between the Jones sand section and the Smackover limestone marked in places by a veneer of gravel. All of this is certainly evidence that there was uplift in this area just prior to the deposition of Cotton Valley sediments. There is still more definite evidence of this age of movement in other fields, for example, Magnolia and Snow Hill.

Figure 16 is an isopach map contoured on the interval from the top of the Cotton Valley formation to the top of the Jones sand. A variation of more than 120 feet in thickness is indicated for this major part of the Cotton Valley formation. Since specific correlations are difficult in this type of formation, it can not be definitely determined whether the thinning of the Cotton Valley formation over the structure is due to truncation, deposition, or a combination of the two. At the south, in northern Louisiana, it appears that there was little or no break in sedimentation between Cotton Valley and Hosston time. At the north, the rapid thinning coupled with thick gravel deposits indicates a definite depositional break with probable truncation. At Schuler the break is definite but probably represents only a disconformity with no erosion. As the local area was definitely

positive before Cotton Valley deposition, it is logical to assume that it remained so throughout Cotton Valley time, resulting in the thin section of Cotton Valley over the field.

The fact that the thinnest point on the Cotton Valley isopach lies northwest of the structural top on both older and younger beds indicates that there may

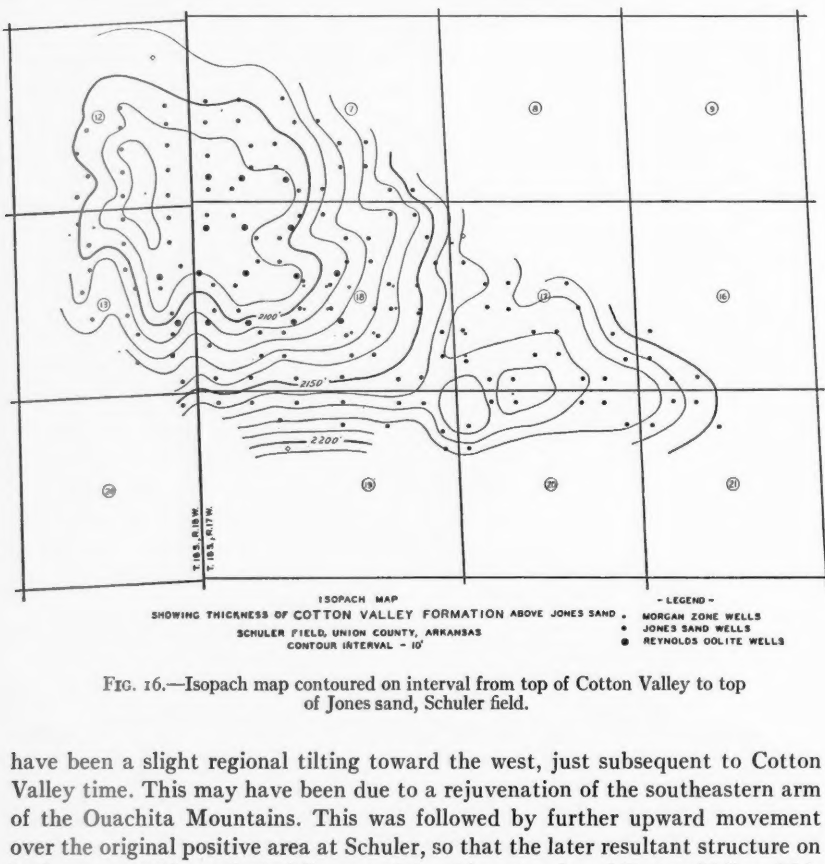


FIG. 16.—Isopach map contoured on interval from top of Cotton Valley to top of Jones sand, Schuler field.

have been a slight regional tilting toward the west, just subsequent to Cotton Valley time. This may have been due to a rejuvenation of the southeastern arm of the Ouachita Mountains. This was followed by further upward movement over the original positive area at Schuler, so that the later resultant structure on both upper and lower beds falls east of the thinnest point of Cotton Valley. This is further borne out, since the structural top on Comanche beds is considerably east of that on older formations. A more marked period of regional tilting westward followed Comanche deposition. This resulted in widespread erosion of Comanche beds, and explains the absence of the Washita, Fredericksburg, Paluxy, Mooringsport, and Ferry Lake formations at Schuler. Since the top of the structure on Gulf beds is slightly west of that on the Comanche beds, it is

apparent that the widespread post-Comanche westward tilting, resulting in the deep erosion, was followed in early Gulf time by some slight tilting toward the east, possibly a little toward the north, thus throwing the original Comanche structure slightly east and north of the Gulf positive area and resultant Gulf structure (Fig. 11).

Although the shifting structure of this area may be subject to various other interpretations, the writers favor the interpretation here given in the light of present data. Regardless of various interpretations, all of the evidence points to a continuously positive area throughout Jurassic and Cretaceous time. The wealth of information from this field, added to that from other recent deep fields in this area, should afford material for a very complete study of the structural history of this region.

WELL DATA

Beginning with the first well, exceptionally complete data were collected on all of the wells in the Schuler field. As a result, a more accurate picture of reservoir conditions can be drawn for this field than for most. The geological and engineering staffs of the Phillips Petroleum Company and the Lion Oil Refining Company coöperated throughout the development period of the field in obtaining as much information as possible about the stratigraphy and the reservoir conditions of the field. In collecting these data, they had the full coöperation of all operators in the field. Subsequently, the Arkansas Oil and Gas Commission supervised and aided in the accumulation of data regarding the productive history of the reservoirs.

The lenticularity of the producing sands in the Morgan zone made it necessary that wells be closely supervised throughout the coring and drilling of this several hundred feet of section. Sand sections were cored wherever possible. Geologists selected sand tops and coring points by timing the drilling. The usefulness of drilling-time charts became so apparent that it became the practice to time all drilling and coring throughout important zones. This not only aided in the construction of stratigraphic logs and the reconstruction of partly recovered cores, but greatly reduced the actual amount of cuttings examination and made it possible to select coring points accurately with a relatively small waste of cores. Figure 17 shows a correlation of plotted time charts through the Jones sand across the field, and indicates the correlation of timing with some other important stratigraphic markers. A reference to Figures 7 and 9 will further show the marked correlation of the time log with core descriptions, core analyses, and electrical logs.

In addition to keeping time logs throughout various zones in practically all wells, geologists made macroscopic descriptions of all cores taken in the field, these later being supplemented in part by microscopic examinations. The two major operators in the field set up core-analysis laboratories and ran core analyses on practically all cores taken from the field. Sampling was usually as close

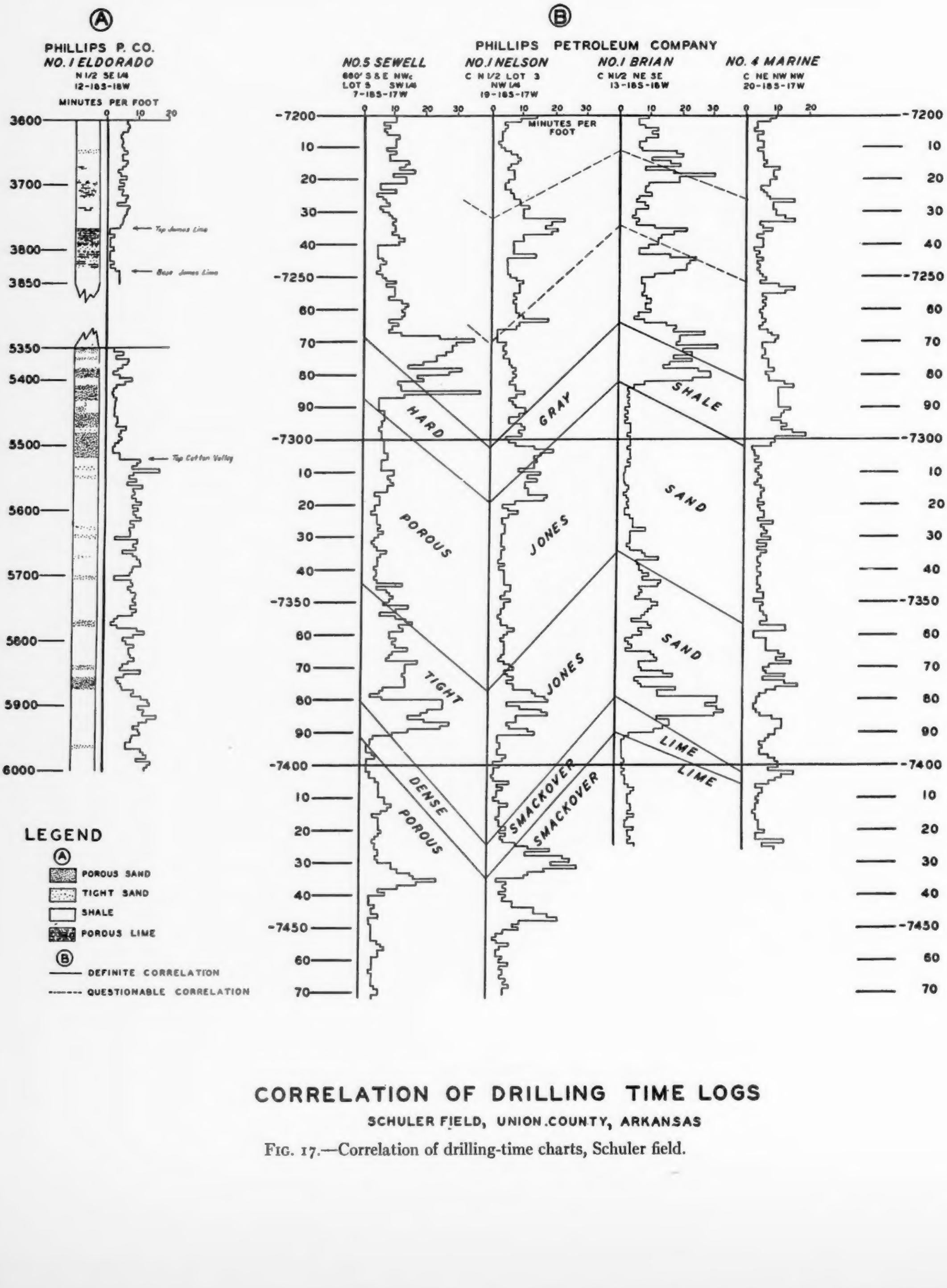


FIG. 17.—Correlation of drilling-time charts, Schuler field.

as one foot. Before final casing was set on wells, electrical logs were obtained. These were a distinct aid in selecting tops and correcting measurements. They were of very little use in determining the type of fluid in the Jones sand and Reynolds oölite, but were useful for this purpose within the Morgan zone.

Statistical compilations on this type of data have not been made for all zones. However, the following statistics for the Jones sand should be fairly representative. Out of 146 Jones sand wells and 3 dry holes, cores were taken of the Jones sand in 146 wells. The zone was completely cored in 131 wells. Jones sand cores from 126 wells were analyzed, while the complete, cored zone in 116 wells was analyzed. There was 9,827 feet of coring within this zone, with a recovery of 8,292 feet from which 6,974 samples were analyzed. These analyses consisted of determining the porosity, vertical and horizontal permeability, and the nature and amount of the fluid content of the core samples. Electric logs were made through most or all of the Jones sand in 162 wells. All of these data were made available to all operators and were used in determining the correct procedure in completing wells.

PRODUCTION

DEPTH

Depths to the producing zones have been indicated in previous discussion and figures. The practice of drilling the well and setting the oil string of casing through the producing zone was universal in the field. Many of the holes were drilled to 100 feet below the deepest possible production, in order to allow for flexibility in placing tubing to control gas-oil ratios. Final sub-sea depths on Morgan sands producers varied from 5,500 to 5,900 feet. Final sub-sea depths for Jones sand and Reynolds oölite wells varied from 7,360 to 7,493 feet.

INITIAL PRODUCTION

Due to the limited allowable production, there are few data on the open-flow potential of the deeper wells. Data of that type would have had no significance due to the wide variation in the amount of section perforated.

Morgan zone.—The discovery well in the Morgan zone initially flowed 320 barrels of oil per day through $\frac{1}{4}$-inch choke. Other wells, producing from several sands, were completed, flowing as much as 1,500 barrels per day through $\frac{1}{2}$-inch choke. The pressure was quickly dissipated and all wells were on artificial lift by May 28, 1938, 13 months after the completion of the first well.

Leona sand.—Although the discovery well in the Leona sand pumped only 80 barrels of oil per day, a later well flowed at the rate of 428 barrels of oil per day through 13/64-inch tubing choke with tubing pressure at 1,200 pounds per square inch and casing pressure at 1,400 pounds per square inch.

Jones sand.—The discovery well in the Jones sand flowed 2,500 barrels of oil per day through open $2\frac{1}{2}$-inch tubing. The second well produced 4,159 barrels of

oil in 24 hours through $1\frac{1}{2}$-inch tubing choke with tubing pressure of 150 pounds per square inch and casing pressure of 1,050 pounds per square inch.

Reynolds oölite zone.—The first Reynolds oölite zone producer was completed, producing 14 million cubic feet of gas and 300 barrels of distillate per day through $\frac{1}{4}$-inch tubing choke, with tubing pressure at 2,475 and casing pressure at 2,600 pounds per square inch. The first oil well completed in this zone produced 1,216 barrels of oil per day through $\frac{1}{4}$-inch choke.

GAS-OIL RATIOS

Morgan zone.—With the exception of three short-lived gas wells, very little gas was produced with the oil from the Morgan zone. Few gas gauges were taken; however, ratios varied around 800:1.

Jones sand.—Jones sand wells as originally completed had gas-oil ratios varying from 500 to 1,200 cubic feet per barrel. Crowell (2, p. 26) gives the average gas-oil ratio for the first 2 years of production as 972 cubic feet per barrel. It has been calculated that the Jones sand originally contained approximately 762 cubic feet of gas dissolved per barrel of oil. Gas-oil ratios have continued to rise, coincident with and due to the fall in pressure. By June, 1940, the average gas-oil ratio was 2,172:1, with a range of from 400 to 10,163:1. The writers are of the opinion that there is an inverse relationship between the gas-oil ratio and the sum of the unit permeability perforated and producing. The data for this theory are not given here. By February, 1941, when the operation of the Jones pool was taken over as a unit, the net gas-oil ratio for the pool was 2,800:1. Of the 140 wells within the unit, all but 50 were shut in, the same former field allowable being taken from those wells. The net field gas-oil ratio decreased to 1,400:1 in the first week of operation. By July, 1941, the ratio had risen to 1,825:1.

Reynolds oölite.—The discovery well in the Reynolds oölite was completed as a gas well with a gas-oil ratio of about 35,000:1. Subsequent wells were completed with ratios of approximately 700:1. By July, 1940, the ratio averaged 1,000:1.

PRESSURE

Morgan zone.—Since the pressure in the sands of the Morgan zone declined rapidly and was negligible by the time the State Oil and Gas Commission began collecting well data, there is little information regarding reservoir pressures. The original reservoir pressure has been reported as 2,250 pounds per square inch at a sub-sea depth of 5,300 feet (4, p. 11).

Jones sand.—The original reservoir pressure in the Jones sand reservoir was 3,520 pounds per square inch at a sub-sea depth of 7,300 feet. By February 17, 1941, the average pressure was 1,542 pounds per square inch, a total drop of 1,978 pounds. At that time the Jones sand pool was unitized, with the exception of 6 wells. There was a differential of 550 pounds per square inch across the field, at that time, with low pressures and high gas-oil ratios in the southeast part of the field. By August, 1941, when the average pressure was 1,502 pounds per

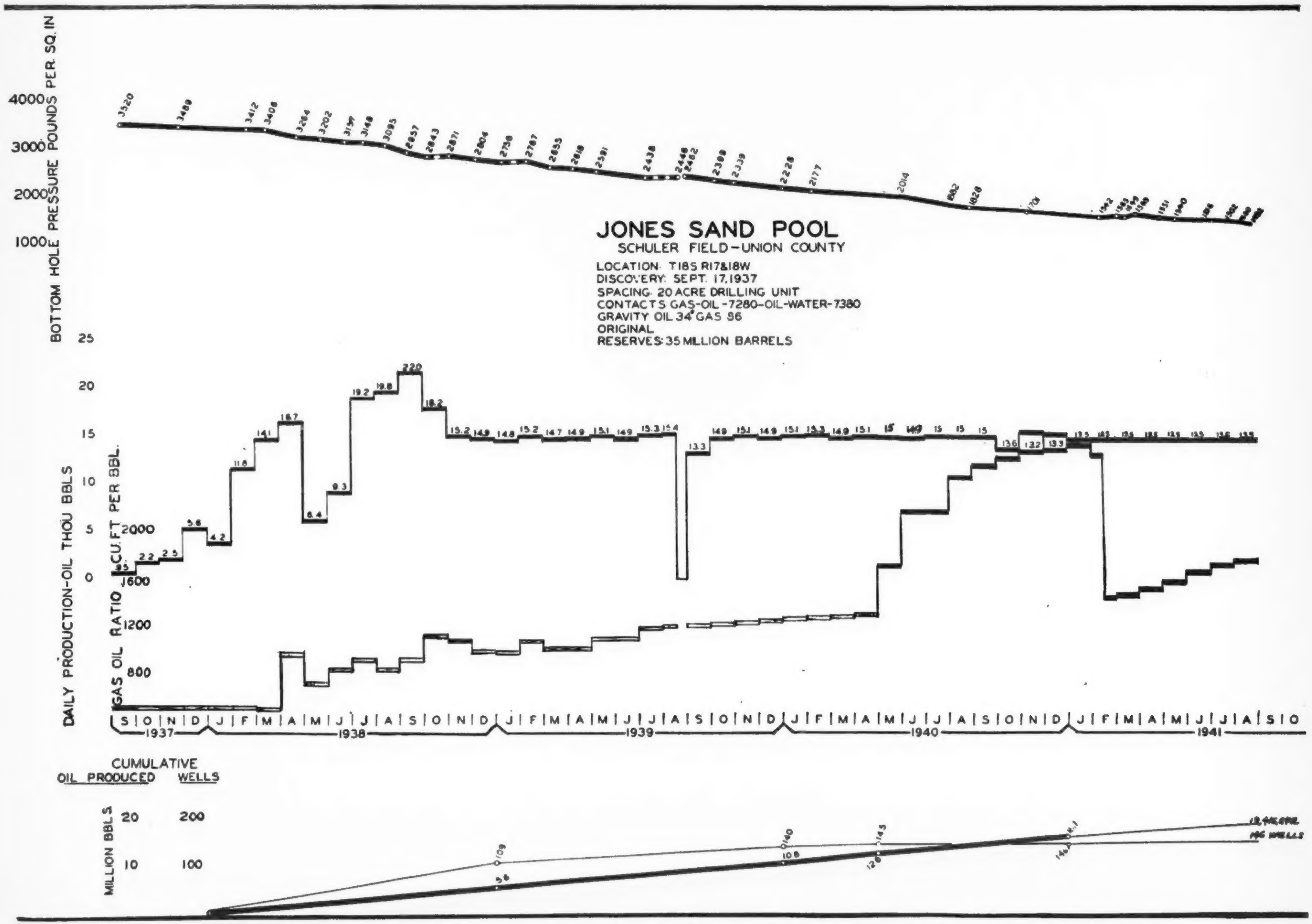


Fig. 18.—Pressure-decline chart, Jones sand, Schuler field. (Reprinted from Arkansas Oil and Gas Commission.)

TABLE I

JONES SAND: PRESSURE, MONTHLY PRODUCTION, GAS-OIL RATIO
(Pressure from control charts end of each month) (3, p. 70)

Date	*Wells*	*Bottom-Hole Pressure (Pounds)*	*Pressure Change*	*Monthly Production (Barrels)*	*Gas-Oil Ratio (Cu. Ft. Per Barrel)*	*Bbls. Oil Recovered Per Pound Pressure Drop*
Sept., 1937	1	3,520		26,553	500	
Oct.	1	3,505	−15	68,051	500	4,537
Nov.	2	3,489	−16	74,268	500	4,642
Dec.	9	3,460	−29	174,695	500	6,024
Jan., 1938	11	3,431	−29	130,230	500	4,491
Feb.	17	3,410	−21	329,277	500	15,680
Mar.	26	3,357	−53	436,988	583	8,245
Apr.	35	3,255	−102	500,470	999	4,907
May	46	3,193	−62	199,066	750	3,211
June	51	3,154	−39	280,218	871	7,185
July	62	3,125	−29	596,283	950	20,561
Aug.	70	3,026	−99	613,799	876	6,200
Sept.	81	2,886	−140	658,524	950	4,704
Oct.	97	2,865	−21	562,748	1,155	26,798
Nov.	105	2,824	−41	455,125	1,099	11,101
Dec.	110	2,774	−50	463,670	1,028	9,273
Jan., 1939	119	2,762	−12	457,837	1,000	38,153
Feb.	122	2,711	−51	426,035	1,025	8,354
Mar.	123	2,633	−78	457,124	1,050	5,861
Apr.	128	2,601	−32	447,030	1,010	13,970
May	130	2,543	−58	467,324	1,115	8,057
June	133	2,468	−75	448,585	1,215	5,981
July	137	2,442	−26	475,434	1,305	18,286
Aug.*	140	2,460	+18	259,754	1,400	
Sept.	140	2,414	−46	398,528	1,200	8,664
Oct.	141	2,376	−38	463,151	1,300	12,188
Nov.	141	2,343	−33	452,982	1,400	13,727
Dec.	141	2,291	−52	463,596	1,500	8,915
Jan., 1940	143	2,235	−56	469,659	1,600	8,387
Feb.	144	2,193	−42	443,566	1,700	10,561
Mar.	144	2,140	−53	464,502	1,825	8,764
Apr.	145	2,081	−59	452,269	1,950	7,666
May	145	2,020	−61	463,637	2,072	7,601
June	145	1,961	−59	450,000	2,172	7,627
July	146	1,902	−59	465,000	2,272	7,881
Aug.	146	1,882	−20	468,441	2,442	
Sept.	146	1,828	−54	452,050		
Oct.	146			425,351		
Nov.	146	1,701		397,472		
Dec.	146			413,213		
Jan., 1941	146			420,062		
Feb.		1,542		376,755	1,350	
Mar.		1,565	+23	417,941	1,300	
Apr.		1,569	+4	406,298	1,459	
May		1,551	−18	419,990	1,592	
June		1,540	−11	404,719	1,744	
July		1,516	−24	422,217	1,871	
Aug.		1,502	−14	416,974	1,780	
Sept.		1,482	−20			

* Field closed in from August 17 to September 4, 1939.

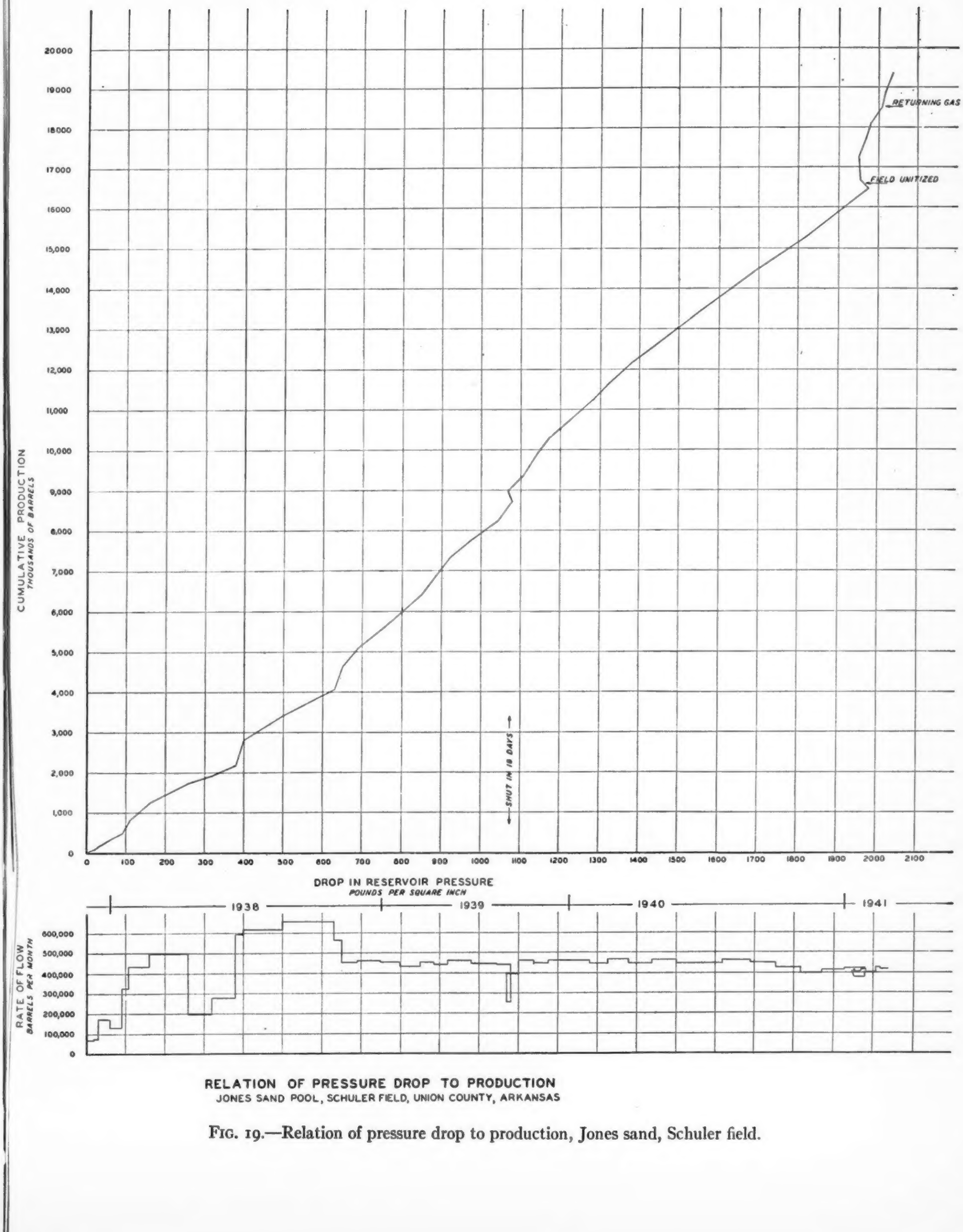


FIG. 19.—Relation of pressure drop to production, Jones sand, Schuler field.

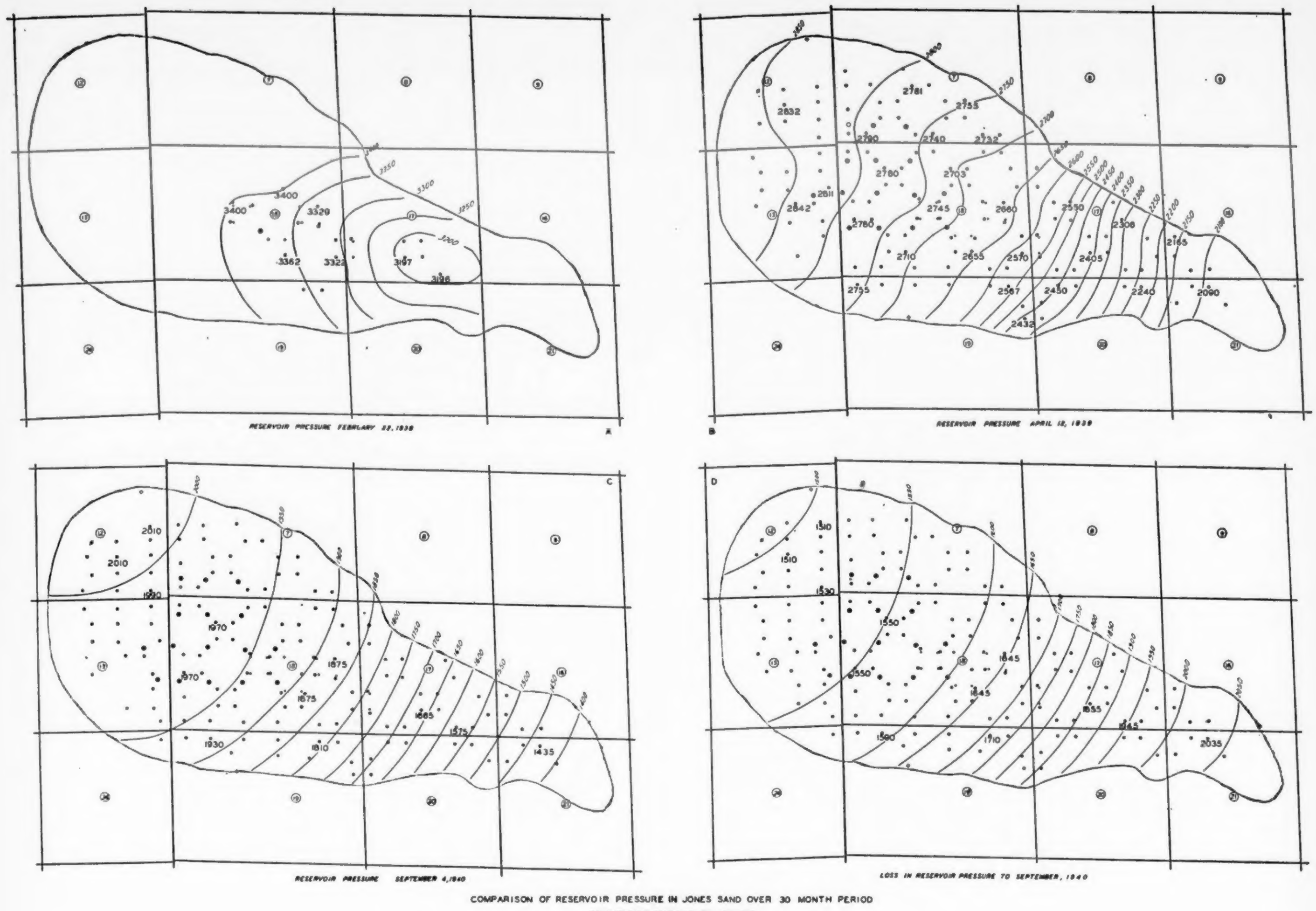


Fig. 20.—Comparison of reservoir-pressure maps, Jones sand, Schuler field.

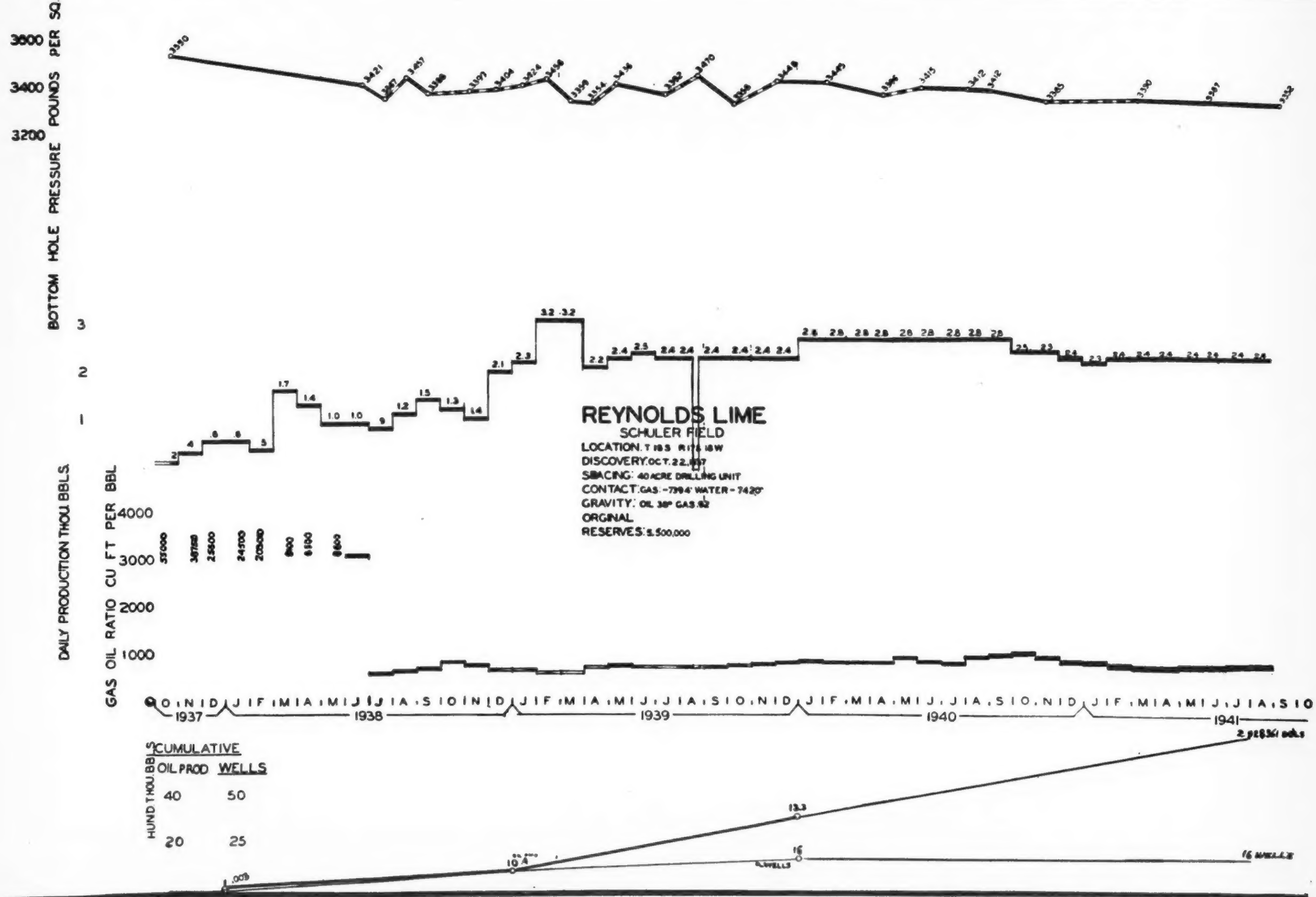


FIG. 21.—Pressure-decline chart, Reynolds oölite, Schuler field. (Reprinted from Arkansas Oil and Gas Commission.)

TABLE II

REYNOLDS OÖLITE: PRESSURE, MONTHLY PRODUCTION, GAS-OIL RATIO
(Pressure from control charts end of each month) (3, p. 71)

Date	*Wells*	*Bottom-Hole Pressure (Pounds)*	*Pressure Change*	*Monthly Production (Barrels)*	*Gas-Oil Ratio (Cu. Ft. Per Barrel)*	*Bbls. Oil Recovered Per Pound Pressure Drop*
Oct., 1937	1	3,530	−20	1,922	55,000	96
Nov.	1	3,510	−20	11,970	38,750	598
Dec.	1	3,490	−20	19,933	25,600	997
Jan., 1938	1	3,480	−10	16,932	24,500	1,693
Feb.	1	3,470	−10	12,722	20,300	1,272
Mar.	2	3,450	−20	51,720	8,100	2,586
Apr.	2	3,440	−10	41,069	6,500	4,107
May	3	3,430	−10	29,842	8,600	2,984
June	4	3,410	−20	30,384	3,200	1,519
July	5	3,410	0	26,279	700	
Aug.	5	3,420	+10	36,584	750	
Sept.	5	3,310	−110	44,304	800	403
Oct.	5	3,360	+50	39,677	931	
Nov.	6	3,400	+40	34,212	871	
Dec.	10	3,415	+15	65,057	770	
Jan., 1939	12	3,440	+25	72,735	782	
Feb.	14	3,410	−30	88,244	710	2,941
Mar.	14	3,350	−60	97,658	709	1,628
Apr.	14	3,395	+45	66,124	825	
May	14	3,420	+25	72,385	870	
June	16	3,400	−20	75,289	855	3,764
July	16	3,420	+20	73,669	855	
Aug.	16	3,460	+40	50,383	850	
Sept.	16	3,380	−80	71,657	850	896
Oct.	16	3,395	+15	73,882	875	
Nov.	16	3,441	+46	73,029	900	
Dec.	16	3,447	+6	72,953	940	
Jan., 1940	16	3,445	−2	86,624	970	43,416
Feb.	16	3,429	−16	81,433	933	5,090
Mar.	16	3,408	−21	87,184	938	4,152
Apr.	16	3,401	−7	83,563	1,002	11,937
May	16	3,413	+12	86,914	1,002	
June	16	3,413	0	84,000	1,025	
July	16	3,400	−13	86,800	1,050	6,677
Aug.*	16	3,412		87,098	1,034	
Sept.	16	3,412		84,074	1,025	
Oct.	16			77,897	1,030	
Nov.	16	3,385		74,983		
Dec.	15			73,488		
Jan., 1941	15			72,653		
Feb.	15			66,072	837	
Mar.	15	3,390		73,738		
Apr.	15			72,290		
May	15			75,118		
June	15	3,387		72,350		
July	15			77,155		
Aug.	15			75,007		

* Data prior to August, 1940, taken from compilation of Arkansas Oil and Gas Commission. Subsequent data added by the writers.

square inch, the differential across the field was reduced to about 100 pounds per square inch. This was largely attained by shutting in the lower-pressure wells on the east side of the field. By shutting in the high gas-oil ratio wells, the daily pressure drop for the field was reduced from 1.7 to 0.7 pounds per square inch in the period from February 17 to July 1. At that time the operators commenced returning gas to the gas cap in 4 wells. Within a few weeks the pressure drop for the reservoir, in pounds per square inch per day, was reduced to 0.3.

Figure 18 shows the early drop in bottom-hole pressure in the Jones sand as related to the rate of production and the gas-oil ratio. Figure 19 is the drop in reservoir pressure as plotted against accumulated production. It is indicated that the recovery of oil in barrels per pounds drop in pressure has remained fairly constant throughout the life of the field to the present time. Table I is a compilation by the Arkansas Oil and Gas Commission (3, p. 70) of production, pressure, and gas-oil ratio data to August, 1940. Subsequent incomplete data have been added by the writers. Figure 20 is a comparison of bottom-hole pressure maps at various stages in the development of the field. The rapid decline in pressure, coupled with the lack of serious water encroachment, is evidence that this is a gas-driven pool.

Reynolds oölite zone.—The original reservoir pressure in the Reynolds oölite zone was 3,530 pounds per square inch at a sub-sea depth of 7,300 feet. By March 1, 1941, the average pressure was 3,390 pounds per square inch, a drop of 160 pounds. Fifteen thousand barrels of oil had been produced per pound loss of pressure since the discovery of the pool. This is comparable with 8,660 barrels of oil produced per pound loss of pressure in the Jones sand, prior to unitization. Table II shows that there has been very little net drop in pressure subsequent to the first 9 months of production, during which time the discovery well was flowing gas at an excessive rate. There is a water drive in this field which seems capable of maintaining a constant reservoir pressure at withdrawals up to 70,000 barrels per month. Figure 21 shows the drop in bottom-hole pressure as related to the production and gas-oil ratio.

ANALYSES OF OIL

In general, the oil from the Morgan zone sands is a more desirable oil than that from the Jones sand or the Reynolds oölite. The Morgan oil has a somewhat higher gravity and contains less sulphur. The gravity of the oil from various Morgan sands showed little variation. The following analyses were made and published by the United States Bureau of Mines (1, pp. 29–31).

MORGAN SAND SAMPLE 38193
(5,588–5,591 Feet)

GENERAL CHARACTERISTICS

Specific gravity, 0.821
Sulphur, per cent, 0.52
Saybolt Universal viscosity at 77°F., 48 sec.
Saybolt Universal viscosity at 100°F., 42 sec.
A.P.I. gravity, 40.9°
Color, brownish black

APPROXIMATE SUMMARY

	Per Cent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	8.4	0.669	80.0	
Total gasoline and naphtha	30.9	0.721	64.8	
Kerosene distillate	18.7	.792	47.2	
Gas oil	10.8	.830	39.0	
Non-viscous lubricating distillate	11.9	.838–.864	37.4–32.3	50–100
Medium lubricating distillate	3.9	.864–.873	32.3–30.6	100–200
Viscous lubricating distillate	—	—	—	Above 200
Residuum	23.3	.948	17.8	
Distillation loss	0.5	—	—	

JONES SAND SAMPLE 38914
(7,506–7,561 Feet)
GENERAL CHARACTERISTICS

Specific gravity, 0.852
Sulphur, per cent, 1.40
Saybolt Universal viscosity at 77°F., 55 sec.
Saybolt Universal viscosity at 100°F., 48 sec.
A.P.I. gravity, 34.6°
Color, greenish black

APPROXIMATE SUMMARY

	Per Cent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	10.4	0.674	78.4	
Total gasoline and naphtha	30.5	0.730	62.3	
Kerosene distillate	9.1	.810	43.2	
Gas oil	14.3	.845	36.0	
Non-viscous lubricating distillate	9.5	.867–.896	31.7–26.4	50–100
Medium lubricating distillate	5.9	.896–.905	26.4–24.9	100–200
Viscous lubricating distillate	—	—	—	Above 200
Residuum	30.2	.972	14.1	
Distillation loss	0.5	—	—	

REYNOLDS OÖLITE SAMPLE 38195
(7,636–7,655 feet)
GENERAL CHARACTERISTICS

Specific gravity, 0.841
Sulphur, per cent, 0.91
Saybolt Universal viscosity at 77°F., 44 sec.
Saybolt Universal viscosity at 100°F., 42 sec.
A.P.I. gravity, 36.8°
Color, greenish black

APPROXIMATE SUMMARY

	Per Cent	Sp. Gr.	°A.P.I.	Viscosity
Light gasoline	10.0	0.679	76.9	
Total gasoline and naphtha	32.3	0.741	59.5	
Kerosene distillate	9.7	.812	42.8	
Gas oil	16.3	.848	35.4	
Non-viscous lubricating distillate	10.2	.867–.893	31.7–27.0	50–100
Medium lubricating distillate	5.7	.893–.903	27.0–25.2	100–200
Viscous lubricating distillate	—	—	—	Above 200
Residuum	24.6	.956	16.5	
Distillation loss	1.2	—	—	

THICKNESS AND RESERVES

Morgan Sand zones.—Due to the lenticular nature of the Morgan zone sands, little information is available as to actual reserves. Sands vary from 1 to 20 feet

in thickness. The aggregate of oil-bearing sands in some wells is as high as 60 feet, although the average is nearer 30 feet. On page 28 of its annual report of January, 1939, the Arkansas Board of Conservation estimated the recoverable reserves for this zone at 4,500,000 barrels of oil. Following is the production by years.

	Barrels
1937 (9 months)	842,255
1938	653,638
1939	319,764
1940	236,912
1941 (1st 6 months)	88,482
Total	2,141,051

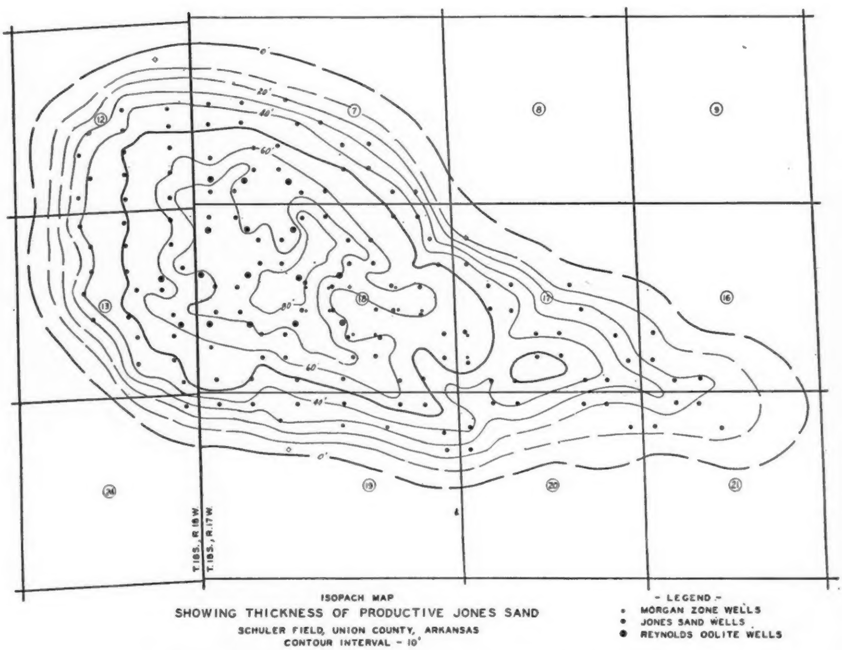


FIG. 22.—Isopach map, Jones sand reservoir, Schuler field.

Leona sand.—By September 1, 1941, two wells in the Leona sand had produced 11,413 barrels of oil.

Jones sand.—Figure 22 is an isopach map showing the net thickness of gas- and oil-bearing Jones sand throughout the Schuler field. The reservoir embraces approximately 4,000 acres. The maximum net thickness of productive sand is 85 feet. The maximum net thickness of oil-producing sand is also 85 feet, and the

maximum net thickness of gas-bearing sand is 17 feet. Figure 23 is an isovol map of the productive Jones sand. The units contoured represent the product of the average porosity and the sand thickness. Since the porosity is taken into account, this map gives a much more accurate picture of the volume of the reservoir than does the isopach map. For instance, the actual void volume in acre-feet between contours 4 and 6 will be the area in acres lying between these contours multiplied

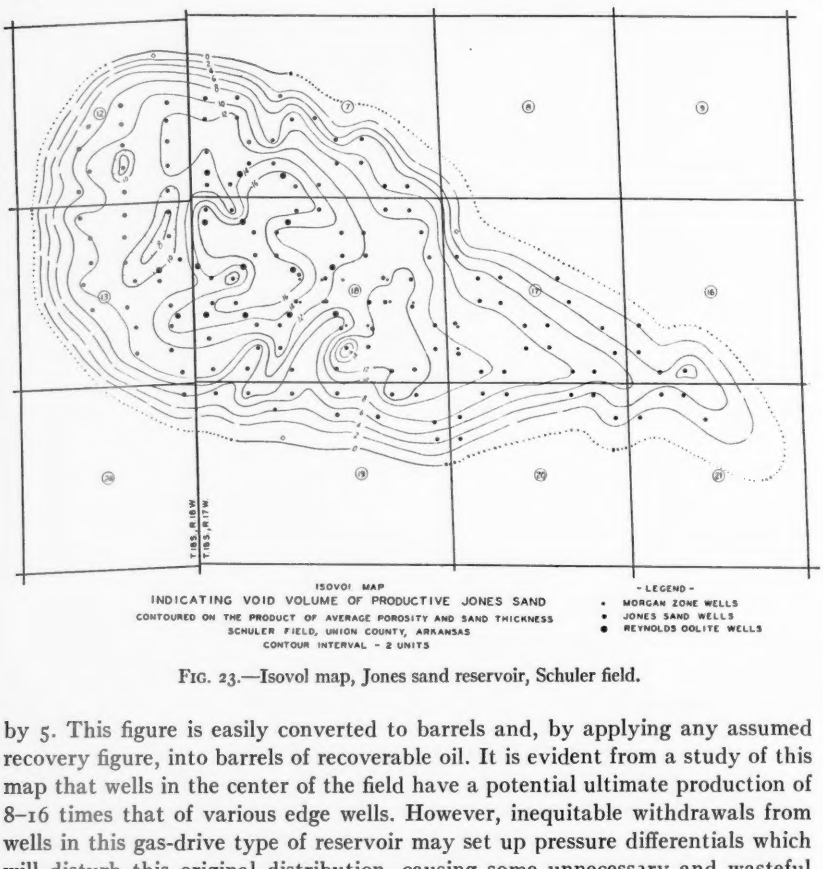


FIG. 23.—Isovol map, Jones sand reservoir, Schuler field.

by 5. This figure is easily converted to barrels and, by applying any assumed recovery figure, into barrels of recoverable oil. It is evident from a study of this map that wells in the center of the field have a potential ultimate production of 8–16 times that of various edge wells. However, inequitable withdrawals from wells in this gas-drive type of reservoir may set up pressure differentials which will disturb this original distribution, causing some unnecessary and wasteful migration of fluid within the reservoir. That this has taken place to some extent in the Jones sand pool is evidenced by the differential in pressure across the field, accompanied by exceptionally high per-acre production from some wells in the area of thin sand and low pressure. Similar maps may be built up for purely gas or oil sections of the reservoirs. These maps demand ample core sampling and

analyzing, but afford more correct data on reserves than could otherwise be obtained.

The Arkansas Oil and Gas Commission has published an estimated 36,500,000 barrels as original recoverable oil from this reservoir (3, p. 53). Production figures are as follows.

	Barrels
1937 (4 months)	333,543
1938	5,203,849
1939	5,213,919
1940	5,345,513
1941 (1st 6 months)	2,445,765
Total	18,542,589

Reynolds oölite.—The maximum net thickness of gas-producing Reynolds oölite is 26 feet. The maximum net thickness of oil-producing oölite is 50 feet. The maximum net productive thickness (including gas) is 52 feet. The reservoir covers an approximate 1,200 acres; however, the productive oölite in much of this area is too thin for commercial production at this depth. The recovery of the oil from these margin areas will depend on the efficiency of the production methods. The Arkansas Oil and Gas Commission has estimated that the original recoverable oil in place was 5,500,000 barrels (3, p. 53). Production figures are as follows.

	Barrels
1937 (2 months)	34,028
1938	416,432
1939	889,242
1940	994,358
1941 (1st 6 months)	432,221
Total	2,766,281

RELATION OF PRODUCTION TO STRATIGRAPHY AND STRUCTURE

Morgan zone.—As shown in Figure 8, the sands of the Morgan zone are lenticular. No one sand can be traced far laterally. It is plain that the lensing sand conditions must largely have controlled the specific accumulation of the oil. However, the general structure of this anticline must have been responsible for the accumulation in general, since wildcat wells through this section of the state, which were not located high structurally, have not had showings of oil in this zone. It is inconceivable that oil should have migrated any great distance in this type of formation. Therefore, we must conclude that the shales of this zone have themselves served as the source beds for this oil. Although this Schuler facies of the Cotton Valley formation has generally been regarded as of non-marine deposition, the upper part of the formation is predominantly gray siliceous shale with intercalations of maroon shale. The lower part of the formation is more definitely "redbed," with red shales and sands predominant down to near the top of the Jones sand. Sands and shales in the Morgan zone contain some small amount of lignite. There are a few fossils present near the top of the zone, associated with the occurence of glauconite. Within 30 miles on the south, this zone is

composed of marine shales and limestones. All in all, it is probable that the silty sediments of this zone were deposited well out in the sea but on a shallow, broad coastal shelf, where the formation of source beds might well be expected.

Jones sand.—Although the character of the Jones sand varies somewhat throughout its known extent, and it pinches down to nearly a feather-edge in the southeast part of the field, the accumulation of oil must have been due to the structural anticline. The Jones sand extends over the entire area drilled, and the thickness at the edges of the field indicates that it may extend some distance south, west, and north. However, it is probable that the sand may be of bar deposition with the thickest accumulation of sand over the positive Schuler area. There is no characteristic of the sand by which it can be recognized away from the Schuler area.

It is possible that the oil may have originated from the immediately overlying gray shale. However, the oil resembles that of the underlying Reynolds oölite more than that of the Morgan zone, and it is the opinion of the writers that at least part of the oil migrated from the Reynolds oölite in the southeast part of the field. There is at least one well in this part of the field where there is no hard limestone cap above the porous oölite. Although there is a separate, closed "high" in this area, the oölite contains no oil even above the oil-water contact of the main "high." This oil-water contact coincides with the top of the porosity at the bottom of the saddle between the two domes. The sand in the southeast area has a predominance of petroleum residue in various streaks throughout the sand section. Throughout the remainder of the field this residue is confined to the vicinity of the oil-water contact, and actually separates the oil from the water. It is possible that this is due to some chemical reaction between the salt water and the oil at the original contact. The more heterogeneous occurrence of the residue in the southeast area may be due to actual oil migration in joints from the oölite below The surrounding residue may be the explanation for the absence of water encroachment in the Jones sand reservoir.

Reynolds oölite.—The accumulation of oil in the Reynolds oölite is very definitely due to the anticlinal structure, since the porous oölite is present over a wide area and has a very apparent water drive. Oil and gas are present in similar structural traps in the oölite of this area. It is probable that the oil originated in the lower half of the Smackover limestone formation. This part of the formation consists of dark, banded limestone with thin partings of argillaceous, carbonaceous material. In practically all places where this zone has been penetrated it was found to contain globules of oil in fractures and bedding planes. Dense limestone streaks below the producing oölite penetrated at Schuler contained globules of oil in the fractures.

FORMATION WATER

Morgan zone.—All wells producing from the Morgan zone sands were making a large percentage of water within a short time after their completion. However, the rapid decline in pressure, as well as the lenticularity of the sands, is evidence

that there is no effective water drive. Some of the water produced may be connate water released with the decline in pressure. Most of the water comes from below the definite oil-water contacts in the sands.

Jones sand.—There has been no water encroachment in the Jones sand reservoir; however, water is known to be present below and beyond the oil. The failure of the water to encroach can be explained as due to the thick seal of petroleum residue separating the oil from the water. Channel water which appeared in a few wells was successfully "squeezed off."

Reynolds oölite.—Water with a normal hydrostatic head is below the oil in the Reynolds oölite. It has very nearly maintained the original pressure in this reservoir. Due to the high vertical permeability of the oölite, the water is very easily coned with the result that a number of the Reynolds wells are producing large quantities of water. Wells producing more than 90 per cent salt water are still flowing natural.

Typical brine analyses are here given. Hydrogen sulphide was present in all Reynolds samples, but noted in only one Jones sample and that in the southeast area where there may be a connection with the underlying oölite. In this connection it may be pointed out that in analyzing gas from the Jones sand wells it was found that hydrogen sulphide was present only in wells producing from below 7,330 feet sub-sea.

WATER ANALYSIS—MORGAN SAND ZONE

Phillips Petroleum Company's Justiss No. 1

		Parts Per Million	*Per Cent*
Total solids		171,062	100.00
Sodium and potassium	*Na* and *K*	45,640	26.68
Calcium	*Ca*	17,291	10.11
Magnesium	*Mg*	1,803	1.05
Chlorides	*Cl*	106,292	62.14
Bicarbonates	HCO_3	0	0
Sulphates	SO_4	36	0.02

Gravity—1.1333

WATER ANALYSIS—JONES SAND

Alice Sidney Oil Company's J. C. Morgan No. 3

		Parts Per Million	*Per Cent*
Total solids		223,917	100.00
Sodium and potassium	*Na* and *K*	54,588	24.38
Calcium	*Ca*	24,960	11.15
Magnesium	*Mg*	4,045	1.81
Chlorides	*Cl*	140,088	62.56
Bicarbonates	HCO_3	76	.03
Sulphates	SO_4	160	.07

Gravity—1.1828

WATER ANALYSIS—REYNOLDS OÖLITE

Phillips Petroleum Company's Brian No. 4

		Parts Per Million	*Per Cent*
Total solids		242,170	100.00
Sodium and Potassium	*Na* and *K*	55,821	23.05
Calcium	*Ca*	31,711	13.10
Magnesium	*Mg*	3,115	1.28
Chlorides	*Cl*	151,200	62.44
Bicarbonates	HCO_3	169	.07
Sulphates	SO_4	154	.06

Gravity—1.2038

Hydrogen sulphide present

DRILLING AND COMPLETION PRACTICE

All wells were drilled with rotary rigs. The average rig used three 125-horse-power boilers fired with an average of 750,000 cubic feet of gas per day, and carrying a steam pressure of 300 pounds per square inch. The draw-works shaft was usually 8 inches. The mud used averaged 32 centipoint viscosity and weighed from 9.8–10 pounds per gallon. It was forced through the drill stem with 800–900

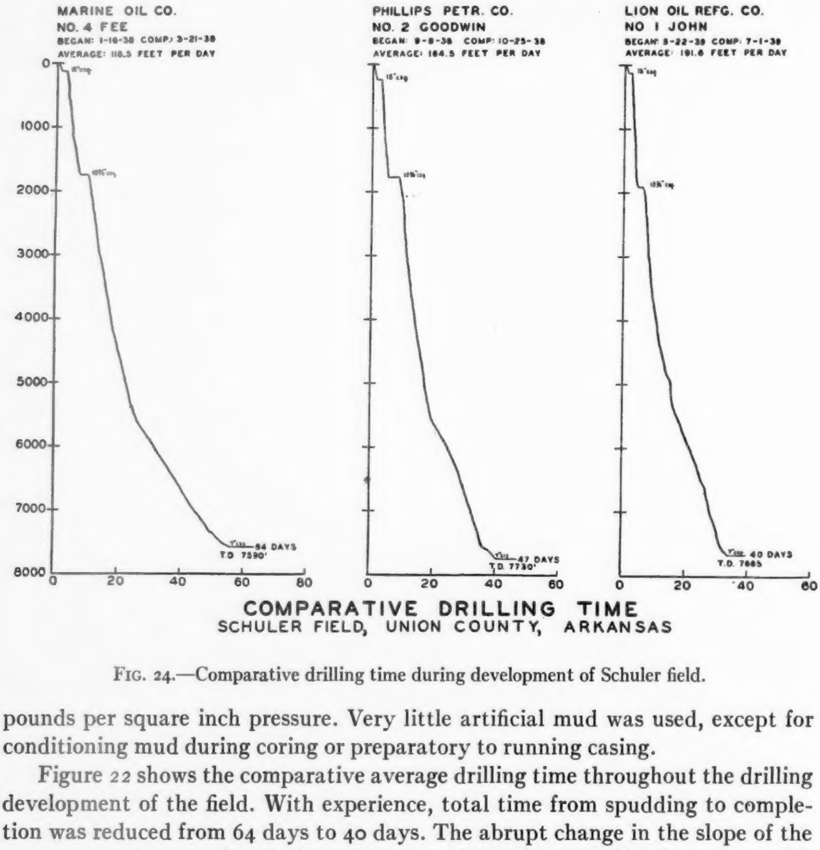


FIG. 24.—Comparative drilling time during development of Schuler field.

pounds per square inch pressure. Very little artificial mud was used, except for conditioning mud during coring or preparatory to running casing.

Figure 22 shows the comparative average drilling time throughout the drilling development of the field. With experience, total time from spudding to completion was reduced from 64 days to 40 days. The abrupt change in the slope of the curve at nearly 5,500 feet indicated the top of the Cotton Valley formation with its hard siltstones and siliceous shales.

SPACING

Under the fear that the law could force one location per 10 acres to hold a lease, all original locations were made as 10-acre locations, 330 feet out of 40-acre

tract corners. By mutual agreement of the operators, alternate locations were skipped. This resulted in the circular pattern shown in Figure 12, which is a very unequal drainage pattern. After the State adoption of more definite oil regulatory laws, the western and later-developed part of the field was drilled in a pattern of wells located in center of elongate 20-acre tracts. This resulted in a somewhat more regular drainage pattern. Costs of drilling and estimates of recoveries have shown that it is not economically feasible to drill wells to this depth in this area on spacing closer than 40 acres.

PRODUCING PRACTICE

The 16-inch surface casing was set in 21-inch hole at depths slightly more than 100 feet, using 125 or more bags of cement. The $10\frac{3}{4}$-inch casing was set as an intermediate and protective string in 15-inch hole, at depths more than 2,000 feet, using 1,000 or more bags of cement. This casing was commonly set in the Saratoga chalk. Early efforts with a shorter protective string were unsatisfactory. In some wells, casing set in the soft caving Midway shales parted during subsequent drilling operations, causing considerable added expense. When this shale is exposed to clear water or non-viscous light mud, it sloughs off in quantity in such manner that the lower end of the casing with its heavy load of cement is left hanging in a cavity. The 7-inch oil string was set in $9\frac{7}{8}$-inch hole, usually below the producing zone. Wells were completed through gun-shot perforations by washing in with water or oil through $2\frac{1}{2}$-inch tubing.

Wells were all brought in under control. They are produced through small choke through the tubing, usually at a regular rate throughout the 24-hour period. Occasionally the daily allowable is produced within a few hours, after which the well is closed in. Wells are produced through separators.

PRODUCTION REGULATION

The history of proration for the Jones and Reynolds pools has been set out in much the following manner by Crowell (2, p. 30).

1. Unregulated, September 17, 1937, to January 1, 1938.
2. Regulated by operators agreement (directed by the Arkansas Board of Conservation), during which period allocations were based on acreage plus pressure, equally weighed, January 1, 1938, to April 1, 1939.
3. April 1, 1939, to present, regulated by a legislative set under the direction of the Arkansas Oil and Gas Commission. Production is allocated on the basis of acreage times pressure with a penalty for gas-oil ratios above a set limit. The wells in the Morgan zone have never been regulated.

ANNOTATED BIOLIOGRAPHY

1. BLADE, O. C., AND BRANNER, GEORGE C., "Survey of Crude Oils of the Fields of Arkansas," *U. S. Bur. Mines R. I. 3486* (January, 1940). Brief history of development of various oil fields, generalized discussion of oil analyses and complete reports on analyses from specific producing zones. Schuler field analyses are listed, pp. 29–31.
2. CROWELL, ALEC M., "Data on Gas-Driven Pool Discloses Characteristics Differing from Water-Driven Reservoirs," *Petroleum Engineer* (October, 1939), pp. 25–30. History of development of Jones sand reservoir, with pertinent production data. General behavior of this closed or strictly gas-driven reservoir is discussed.
3. ———, *et al.*, *Midyear 1940 Survey of the Oil and Gas Industry in Arkansas* (Arkansas Oil and Gas Commission, Little Rock, August 15, 1940). Data originally prepared for National Defense

Commission, discusses history of oil and gas development in Arkansas, and of production regulation. Data on production, marketing, pipe lines, and analyses. Pp. 68–73, pertinent data and charts on Schuler field.

4. ———, *Preliminary Report on a Study of Factual Information Concerning the Jones Sand Pool of the Schuler Field* (Arkansas Oil and Gas Commission, Little Rock, April 22, 1940). Detailed data on production and pressure in reservoir. Relationship of data shown by charts and maps.
5. EASTON, HARRY D., JR., "Ark-La-Tex Today and Tomorrow," *Oil Weekly* (March 28, 1938). General columnar section at Schuler, showing nomenclature and correlations as understood at that time.
6. HAZZARD, ROY T., "The Centerpoint Volcanics of Southwest Arkansas a Facies of the Eagle Ford of Northeast Texas," *Guidebook of Fourteenth Annual Field Trip Shreveport Geological Society* (Shreveport, Louisiana, 1939), pp. 133–48. Evidence for age of basal Gulf Cretaceous formation, variously known as Centerpoint, "Bingen," and "Woodbine," correlative with Eagle Ford. Author has continued to gather data to support this correlation, and now advocates abandoning all other formation names in favor of Eagle Ford (personal communication).
7. IMLAY, R. W., "Lower Cretaceous and Jurassic Formations of Southern Arkansas and Their Oil and Gas Possibilities," *Arkansas Geol. Survey Inform. Cir. 12* (Little Rock, 1940). Excellent discussion of pre-Gulf stratigraphy, gives evidence for age of formations. First publication of new nomenclature proposed by Shreveport Geological Society as being more applicable to subsurface of immediate area than correlated names from much thinner surface section, if present.
8. SPOFFORD, H. N., *Private Report* (1925). Discusses subsurface structure of "Schuler-Wesson" anticline and recommends test well in Sec. 9, T. 18 S., R. 17 W. Map shown as Figure 2 in present paper. Map made after drilling of two more wells shown as Figure 3.
9. SPOONER, W. C., "Oil and Gas Geology of the Gulf Coastal Plain of Arkansas," *Arkansas Geol. Survey Bull. 2* (Parke-Harper Printing Company, Little Rock, 1935). Plate XX, republished herein, shows structure of Union County as known at that time. Nose across Schuler area shown.
10. TRIPLETT, GRADY, "History of Arkansas," *Oil Weekly* (March 28, 1938), pp. 68–88. Brief history of oil development in Arkansas leading to Schuler discovery. Basic data on field.
11. WEBER, GEORGE, "Sound Conservation Measures Aiding in Schuler Recovery," *Oil and Gas Jour.* (February 23, 1939), pp. 86–89. Production in relation to pressure at that time, and effects of production regulation.
12. WEEKS, WARREN B., "South Arkansas Stratigraphy with Emphasis on the Older Coastal Plain Beds," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 8 (August, 1938), pp. 953–83. Subsurface stratigraphy. Nomenclature has subsequently been somewhat revised.
13. ———, "Schuler Pool, Union County, Arkansas," *Guidebook of Fourteenth Annual Field Trip of Shreveport Geological Society* (Shreveport, Louisiana, June, 1939), pp. 24–27. Brief discussion of structural geology and stratigraphy of field.

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THICKNESS AND STRUCTURAL STUDY OF MAJOR DIVISIONS OF CRETACEOUS SYSTEM IN NEBRASKA[1]

PAUL FUENNING[2]
Lincoln, Nebraska

ABSTRACT

The purpose of this paper is to present isopach maps of certain stratigraphic divisions of the Cretaceous system and structure-contour maps of certain horizons of that system in Nebraska. Tables of factual data also are included. The maps indicate clearly that certain structural "highs" such as the Chadron-Cambridge axis and the Sioux Falls "high," in conjunction with a large well defined basin across central Nebraska and another deep basin west of the Chadron-Cambridge axis, dominated the structural and depositional history of Nebraska during the Cretaceous period.

INTRODUCTION

The purpose of this study is two-fold. First, to determine the variation in thickness of certain divisions of the Cretaceous system as shown by a series of isopach maps. These divisions are the Pierre shale, the Niobrara formation, the Benton group, the "Dakota group," and finally the Cretaceous system as a whole. Second, the determination of the general structure of certain key formations is undertaken. The surfaces mapped are the top of the Niobrara formation, the base of the Fort Hays limestone, the top of the Greenhorn limestone, and the top of the "Dakota group" of sandstones. Collectively, the maps prepared show the relation of variations in thickness to the general structural pattern of the region studied.

ACKNOWLEDGMENTS AND EARLIER WORK

The writer is indebted to the Nebraska State Geological Survey and especially to E. C. Reed, assistant State geologist, who supplied unpublished information on recent wells and assisted generously in the preparation of the isopach and structural maps, and who also aided in the correlation of controversial well logs.

Isopach maps of the Cretaceous and Comanche systems of the United States were published by W. A. Ver Wiebe (1933) and M. K. Elias (1931) included an isopach map of the original thickness of the Pierre of the mid-western states in his report on Wallace County, Kansas.

The contour map of the pre-Cambrian surface by A. L. Lugn (1934) has been of especial interest in connection with this study. The surfaces of the key formations of the Cretaceous reveal a definite relationship with respect to "highs" and "lows" on the surface of the pre-Cambrian.

N. H. Darton (1905) published a structural map of the top of the Dakota sandstone in the Central Great Plains. However, the Nebraska part of the map was largely hypothetical because of the scarcity of subsurface information at the time of publication.

[1] A graduate thesis prepared under the direction of A. L. Lugn, professor of geology, University of Nebraska. Manuscript received, November 14, 1941.

[2] Graduate student in geology, University of Nebraska.

The foregoing references include all previously published material on isopach and structural studies in Nebraska known to the writer. Subsurface cross sections of Cretaceous formations in Nebraska have been published by N. H. Darton (1903, 1918), G. E. Condra (1907), A. L. Lugn (1934), C. T. Jones (1940), G. E. Condra and E. C. Reed (1936), and G. E. Condra, E. C. Reed, and O. J. Scherer (1941).

SOURCE OF INFORMATION

Much of the information on the deep wells of the state used in this paper is taken from "Deep Wells of Nebraska" (Condra, Schramm, and Lugn, 1931). Unpublished information on wells of later date was secured from the Nebraska Geological Survey through E. C. Reed, assistant State geologist. *Professional Paper 32* of the United States Geological Survey (Darton, 1905) was also used as a reference.

Some correlations of Nebraska wells have been revised by the Nebraska Geological Survey on the basis of new information and the revised data have been used. Edwards No. 1 (NW. ¼, SW. ¼ of Sec. 13, T. 2 N., R. 22 W.); Moberry No. 1 (center of NE. ¼, NE. ¼ of Sec. 25, T. 7 N., R. 2 E.); Jones No. 2 (Sec. 29, T. 35 N., R. 47 W.); and the Dannebrog (SE. ¼, SE. ¼, SW. ¼ of Sec. 2, T. 13 N., R. 11 W.) whose logs were listed but not correlated in the "Deep Wells of Nebraska," were given tentative correlations. All of the tentative correlations and changes in the interpretation of previously published logs were approved by the State Geological Survey of Nebraska.

The nature of the information used as a basis for correlation is indicated in Table II. The information from the Stuehm No. 1 (center of NW. ¼, NW. ¼ of Sec. 21, T. 14 N., R. 37 W.), Hall No. 1 (SE. ¼, SE. ¼ of Sec. 10, T. 23 N., R. 49 W.), Armour No. 1 (center of NW. ¼, NE. ¼ of Sec. 33, T. 28 N., R. 8 E.), Mathis No. 1 (NE. ¼ of Sec. 22, T. 5 N., R. 1 W.), and Palmer No. 1 (SW. ¼, NW. ¼ of Sec. 1, T. 33 N., R. 50 W.) was used in preparing the maps, but because these wells were still drilling or were not officially abandoned at the time this paper was written, exact figures were not available. The logs of these wells and samples from many of them are on file at the Nebraska State Geological Survey.

EXPLANATION OF TABLES AND MAPS

The exact locations of the key wells used in this study are shown in Table I. All wells are numbered for convenience in reference to tables and maps. Thickness and structural data on the Pierre shale, Niobrara formation, the Benton group, the "Dakota group," and the Cretaceous system are shown in Table II. A tabulation of the thicknesses of all the Cretaceous formations in the various wells employed in this study is included in Table III.

Contours on the isopach maps represent theoretical points of equal thickness of the interval covered by each map. Likewise, contours on the structural maps represent theoretical points of equal elevation, referred to mean sea-level. In

TABLE I

Wells Used in Isopach and Structural Studies

Name		*Location*	*Key*
1. J. M. Huber Corp., Morgan 1	C SW SW	32-35N-56W	2B*
2. Wm. Erbe, Pinney 1	NW¼ NW¼	13-32N-52W	4A
3. Nebraska Oil Corp., Duthie 1		33-35N-47W	4A
4. Clear Oil Co., Jones 2		29-35N-47W	4A
5. "Slim Butte"		11N-10E, So. Dak.	1A
6. Union Oil Co. of Calif. Agate 15-1	NW/c SE SE	15-28N-55W	2B
7. Felmont Corp., Kinion 1	SW/c NE	21-27N-55W	2B
8. Prairie Oil and Gas Co., Kelley 1	NE/c	33-19N-55W	4A
9. Stephens Oil Co., Palmer 1	SW/c NW	1-33N-50W	3
10. Byrd-Frost Inc., Abbott Estate 1	NE/c NW	22-24N-38W	2B
11. Lakeside Development Co., Lunsford 1	C NL SW SW	17-24N-44W	4A
12. C. L. Price, Hall 1	SE¼ SE¼	10-23N-49W	3A
13. 20th Century Oil Co. Ltd., Stuehm 1	C NW NW	21-13N-37W	3
14. Chase Petroleum Co., Ingold 1	C NE	24- 6N-38W	2B
15. C. L. Price, Carter 1	SE/c NE SW	35- 2N-32W	2B
16. Nebraska Oil Corp., Bauer 1	SE/c SW SW	2- 2N-29W	2B
17. Red Willow Oil and Gas Co., Watkins 1	NE/c NW NW	13- 5N-26W	1B
18. Phillips Pet. Co., Andrews 1	SW/c NW NW	3- 2S-42W, Colorado	1B
19. I.T.I.O. Co., Strangways 1	SE/c NE	21- 2S-43W, Colorado	2B
20. I.T.I.O. Co., Vorce 1	C NE NE	28- 1S-49W, Colorado	2B
21. Helmerich and Payne, Hansen 1	C SW NW	25-15N-31W	2B
22. Scott, Henggler 1	C SE	34- 7N-27W	1A
23. D. B. Cogswell, Holmes 1	NW/c	24- 2N-22W	2A
24. Gilbreath Pet. Co., Edwards 1	NW/c SW	13- 2N-22W	4A
25. Trees Pet. Co., Bergman 1	C SW	23- 6N-19W	2B
26. Marland Oil Co., Reager 1	SW/c NE NW	25- 2S-26W, Kansas	1A
27. Ohio Oil Co., Avery 1-A	SE/c	30- 1N-13W	1B
28. Frost Drilling Co., Kolb 1	SW/c	22- 2N-13W	2A
29. U. S. Drilling Co., Brunke 1	NE/c SW NE	2- 3N-13W	4B
30. Big Chief Oil Co., Hosner 1	NW/c SE NE	35- 2N-11W	1A
31. C. L. Price, Platte 1	C SE	3- 1N-11W	1B
32. Prunty Production Co., Katzberg 1	C SW	26- 7N-10W	2B
33. Jayhawk Prod. and Ref. Co., Shoemaker 1	NE/c	26-12N- 8W	1B
34. "Silver Creek"	NE¼	1-15N- 4W	1A
35. Page *et al.*, Bonham 1	C SE SE	31- 1N- 1E	2B
36. North Central Oil Co., Leonard 1	NE	14-32N-18W	2B
37. Bloomfield Oil and Gas Co., Stahl 1	NE¼	9-30N- 3W	1A
38. "Niobrara"		16-32N- 6W	1A
39. "Santee"		13-33N- 5W	1A
40. "Lynch"		14-33N-10W	1A
41. Foraker and Gish, Moberry 1	C SL NE NE	25- 8N- 2E	4A
42. Wm. Ebke, Mathis 1	NE/c	22- 5N- 1W	3
43. Peder Skriver, Armour 1	C NW NE	33-28N- 8E	3
44. Midland Oil Co., Forster 1-A	SE/c NE	5-16N- 8E	5B
45. "Dannebrog"	SE¼ SE¼ SW¼	2-13N-11W	4A
46. Ohio Oil Co., Demmer 1		15-31N-46W	6B
47. Phillips Petrol. Co., Simmons 1	C NW SE	21-10N-22W	2A

Identification of Key Numbers

A. Driller's log.
B. Sample log.
1. *Nebraska Geol. Survey Bull. 4*, 2d Ser.
2. Unpublished record of Nebraska Geological Survey.
3. Confidential information (samples on file, Nebraska Geological Survey).
4. Revised correlation of Nebraska Geological Survey (previously published).
5. *Nebraska Geol. Survey Paper 13.*
6. *Kansas Geol. Soc. Guide Book, 14th Annual Field Conference* (1940).
2B*. Unpublished sample log of Nebraska Geological Survey.

TABLE II

THICKNESSES AND ELEVATIONS (IN FEET) USED ON ISOPACH AND STRUCTURAL MAPS

Name	Pierre	Niobrara	Benton group	"Dakota group"	Cretaceous	Top of Niobrara	Base of Ft. Hays	Top of Greenhorn	Top of Dakota
1. Morgan 1	1,032	268	1,175	295	2,770	2,960	2,692	2,318	1,517
2. Pinney 1	1,450	220	850	418	2,938	1,955	1,735	1,385	855
3. Duthie 1	0	0	925	295	1,220				2,080
4. Jones 2	0	0	1,102—	328	1,430				1,978
5. "Slim Butte"	0	0	1,385	335	1,720				
6. Agate 15–1	2,675	265	725	340	4,005	1,070	805	455	80
7. Kinion 1	2,870	360	640	350	4,220	895	535	295	−105
8. Kelley 1	3,395	660	1,063	34†	5,152	560	−100	−550	−1,163
9. Palmer 1*									
10. Abbott 1	0	0	40	645	685	x	x	x	1,760
11. Lunsford 1	315	286	599	410	1,610	2,032	1,746	1,362	1,147
12. Hall 1*									
13. Stuehm 1*									
14. Ingold 1	1,290	505	270	710	2,775	1,584	1,070	924	809
15. Carter 1	689	428	365	562	2,044	1,978	1,550	1,322	1,185
16. Bauer 1	217	428	462	418?	1,525?	2,263	1,835	1,595	1,373
17. Watkins 1	0	305	445	415	1,165	2,360	2,055	1,835	1,610
18. Andrews 1	1,430	610	400	545	2,985	2,013	1,403	1,213	1,003
19. Strangways 1	976	564	410	480	2,430	2,091	1,527	1,366	1,126
20. Vorce 1	2,565	490	393	448	3,896	1,565	1,075	915	682
21. Hansen 1	120	320	550	590	1,580	2,090	1,770	1,590	1,220
22. Henggler 1	0	430	550	410	1,390	2,410	1,980		1,430
23. Holmes 1	0	432	375	365	1,172	2,107	1,675	1,512	1,300
24. Edwards 1	0	449	435	297	1,181	2,078	1,629	1,489	1,104
25. Bergman 1	300	440	400	510	1,650	1,645	1,205	935	805
26. Reager 1	0	450	750	420	1,620	2,331	1,881	1,464	1,131
27. Avery 1	0	380	467	353	1,200	1,928	1,548	1,228	1,081
28. Kolb 1	0	362	485	353?	1,200?	1,817	1,455	1,130	970
29. Brunke 1	70	415	410	455	1,350	1,810	1,395	1,100	985
30. Hosner 1	0	220	400	363	983	1,761	1,541		1,141
31. Platte 1	0	172	448	315	935	1,692	1,520	1,192	1,072
32. Katzberg 1	0	264	400	400	1,064	1,619	1,355	1,065	955
33. Shoemaker 1	0	400	375	535	1,310	1,653	1,253	1,063	878
34. "Silver Creek"	0	0	0	325?	800?	1,468		1,148	993
35. Bonham 1	0	0	155	421	576			1,595	1,440
36. Leonard 1	655	230	245	445	1,575	1,247	1,017	842	772
37. Stahl 1	255	214	303	406	1,178	1,338	1,124	964	821
38. "Niobrara"	0	160	327	313?	800?	1,180	1,020	810	693?
39. "Santee"		217	325	341?	883?				
40. "Lynch"				323?	905			812	
41. Moberry 1	0	0	145	355	500			1,435	1,290
42. Mathies 1*									
43. Armour 1*									
44. Forster 1	0	0	0	211	211				1,093
45. "Dannebrog"	215	350	?	?	?	1,455	1,105	880?	
46. Demmer 1	0	0	0	0	0	x	x	x	
47. Simmons 1	0	270	320	590	1,180	2,031	1,761	1,561	1,441

* Confidential information withheld from publication.

† Estimated total thickness of Dakota group, 350 feet.

TABLE III

THICKNESS (IN FEET) OF CRETACEOUS FORMATIONS IN KEY WELLS

	(1) *Morgan 1*	(2) *Pinney 1*	(3) *Duthie 1*[2]	(4) *Jones 2*	(5) *"Slim Butte"*	(6) *Agate 15-1*	(7) *Kinion 1*
Ground elevation	3,992	3,655	3,025	3,150	?	4,705	4,745
Mantle rock[1]	0	250	20	70	0	960	980
Pierre shale	1,032	1,450	0	0	0	2,675	2,870
Niobrara fm.	268	220	0	0	0	265	360
Carlile shale	374	350	0	?	500	350	240
Greenhorn ls.	121	80	0	?		35	90
Graneros sh.	680	420	925	1,102—	885	340	310
Dakota group	295	418	295	328	335	340	350
Total depth	3,999	3,188	2,947	1,860	2,445	6,846	6,500

	(8) *Kelley 1*	(9) *Palmer 1*[3]	(10) *Abbott 1*	(11) *Lunsford 1*	(12) *Hall 1*[3]	(13) *Stuehm 1*[3]	(14) *Ingold 1*
Ground elevation	4,500		3,750	3,887			3,214
Mantle rock[1]	545		1,950	1,540			340
Pierre shale	3,395		0	315			1,290
Niobrara fm.	660		0	286			505
Carlile shale	450		0	384			155
Greenhorn ls.	85		0	45			45
Graneros sh.	528		40	170			70
Dakota group	34[4]		645	410			710
Total depth	5,697		4,040	3,392			4,355

	(15) *Carter 1*[2]	(16) *Bauer 1*[2]	(17) *Watkins 1*	(18) *Andrews 1*	(19) *Strangways 1*	(20) *Vorce 1*	(21) *Hansen 1*[2]
Ground elevation	2,795	2,655	2,360	3,443	3,597	4,360	3,020
Mantle rock[1]	128	175	0	0	530	230	810
Pierre shale	689	217	0	1,430	976	2,565	120
Niobrara fm.	428	428	305	610	564	490	320
Carlile sh.	228	240	220	190	170	160	180
Greenhorn ls.	102	30	75	30	100	45	100
Graneros sh.	35	192	150	180	140	188	270
Dakota group	562	418?	415	545	480	448	590
Total depth	4,464	1,445	3,423	5,130	5,595	7,300	3,828

[1] Mantle rock: includes strata younger than Cretaceous, that is, Pleistocene, Tertiary.
[2] Wells reaching the pre-Cambrian.
[3] Confidential information withheld from publication.
[4] Estimated total thickness of the Dakota group, 350 feet.

TABLE III—*Continued*

THICKNESS (IN FEET) OF CRETACEOUS FORMATIONS IN KEY WELLS

	(22) *Hengler 1*	(23) *Holmes 1*	(24) *Edwards 1*	(25) *Bergman 1*[2]	(26) *Reager 1*[3]	(27) *Avery 1*	(28) *Kolb 1*
Ground elevation	2,480	2,240	2,139	2,345	2,591	1,928	1,870
Mantle rock[1]	70	133	61	400	260	0	53
Pierre shale	0	0	0	300	0	0	0
Niobrara fm.	430	432	449	440	450	380	362
Carlile sh.		163	140	270	417	320	325
Greenhorn ls.	550	67	35	40	34	30	10
Graneros sh.		145	260	90	299	117	150
Dakota group	410	365	297	510	420	353	353?
Total depth	3,005	1,440	3,109	5,678	3,986	4,252	1,110

	(29) *Brunke 1*	(30) *Hosner 1*	(31) *Platte 1*	(32) *Katzberg 1*	(33) *Shoemaker 1*	(34) *"Silver Creek"*	(35) *Bonham 1*
Ground elevation	2,100	1,761	1,727	1,945	1,783	1,565	1,610
Mantle rock[1]	220	0	35	326	130	97	15
Pierre shale	70	0	0	0	0	0	0
Niobrara fm.	415	220	172	264	400	320	0
Carlile sh.	295		328	290	190		
Greenhorn ls.	35	400	45	60	95	65	110
Graneros sh.	80		75	50	90	90	45
Dakota group	455	363	315	400	535	325?	421
Total depth	3,385	3,500	3,446	4,005	1,440	687	3,344

	(36) *Leonard 1*[2]	(37) *Stahl 1*	(38) *"Niobrara"*	(39) *"Santee"*	(40) *"Lynch"*	(41) *Moberry 1*	(42) *Mathies 1*[3]
Ground elevation	2,042	1,700	1,220		1,400	1,470	
Mantle rock[1]	140	107	40	23	18	35	
Pierre shale	655	255	0	0		0	
Niobrara fm.	230	214	160	217	470	0	
Carlile sh.	175	160	210	205		0	
Greenhorn ls.	32	30	32	120	22	65	
Graneros sh.	38	113	85		90	80	
Dakota group	445	406	313?	341?	323?	355	
Total depth	1,715?	1,285	656	606	923	1,730	

	(43) *Armour 1*[3]	(44) *Forster 1*	(45) *"Dannebrog"*	(46) *Demmer 1*	(47) *Simmons 1*
Ground elevation		1,373	1,870	?	2,441
Mantle rock[1]		280	200	?	400?
Pierre shale			215	0	0
Niobrara fm.			350	0	270
Carlile sh.			225	0	200
Greenhorn ls.				0	40
Graneros sh.				0	80
Dakota group		211		0	590
Total depth		2,204	1,011	?	4,500

wells where the formation studied is absent and younger and older beds occur, a zero is inserted on the isopach maps and an *x* on the structural maps. Approximations of elevations and thicknesses had to be made because of inadequate data in some instances, and the figures used in these cases are followed by question marks.

The Benton group includes the Carlile shale, the Greenhorn limestone, and the Graneros shale. The "Dakota group" in this paper includes the "Dakota" (Fall River) formation, the Fuson shale, and the Lakota sandstone. The "Dakota" and Benton groups were used because it was thought that they represent more distinctive sedimentary units than any of their subdivisions and their correlations are subject to less error. The horizons used for structural mapping were selected because of their more certain identity in the well logs.

Outcrop areas of the individual formations or groups are shown on the maps. Since much of the eastern part of the state is covered by Pleistocene deposits, these outcrop areas do not represent the actual surface outcrop but merely indicate, except along some river valleys, the first bed rock to be encountered below the Pleistocene materials. The outcrop areas are taken from the preliminary geologic map of Nebraska, a manuscript copy of which was made available by the Nebraska State Geological Survey.

DESCRIPTION OF FORMATIONS

No detailed lithologic study of the Cretaceous formations was made in connection with this paper. However, a brief general description of the formations is given.

The Pierre shale is predominantly dark gray to dark blue shale with some thin beds of sandstone, limestone, concretionary material, and bentonite.

The upper and middle parts of the Niobrara formation are primarily gray to dark gray, speckled, calcareous shale. The lower part of the Niobrara, referred to as the Fort Hays, is light gray to white chalky limestone.

The Benton group is composed of three formations, the upper one being the Carlile shale, the middle is known as the Greenhorn limestone, and the lower formation is the Graneros shale. The Carlile shale is largely dark gray to black in color, and in many places includes a sandy zone (Codell) at or near its top, becoming calcareous near the base. The Greenhorn limestone is mainly light to dark gray to brownish, fossiliferous, thin-bedded limestone with interbedded layers of calcareous shale. The Graneros shale is medium gray to dark gray in color and is in most places sandy in the basal part.

The lowest major division of the Cretaceous in Nebraska has been known for many years as the "Dakota group." This so-called "group" consists of formations which belong to the Comanche and Dakota series, and it is not a truly valid group. However, the general lithologic similarity throughout and the difficulty, at least locally, encountered in separating this "group" satisfactorily seem to justify the continuance of the old usage, at least it is suitable for this paper.

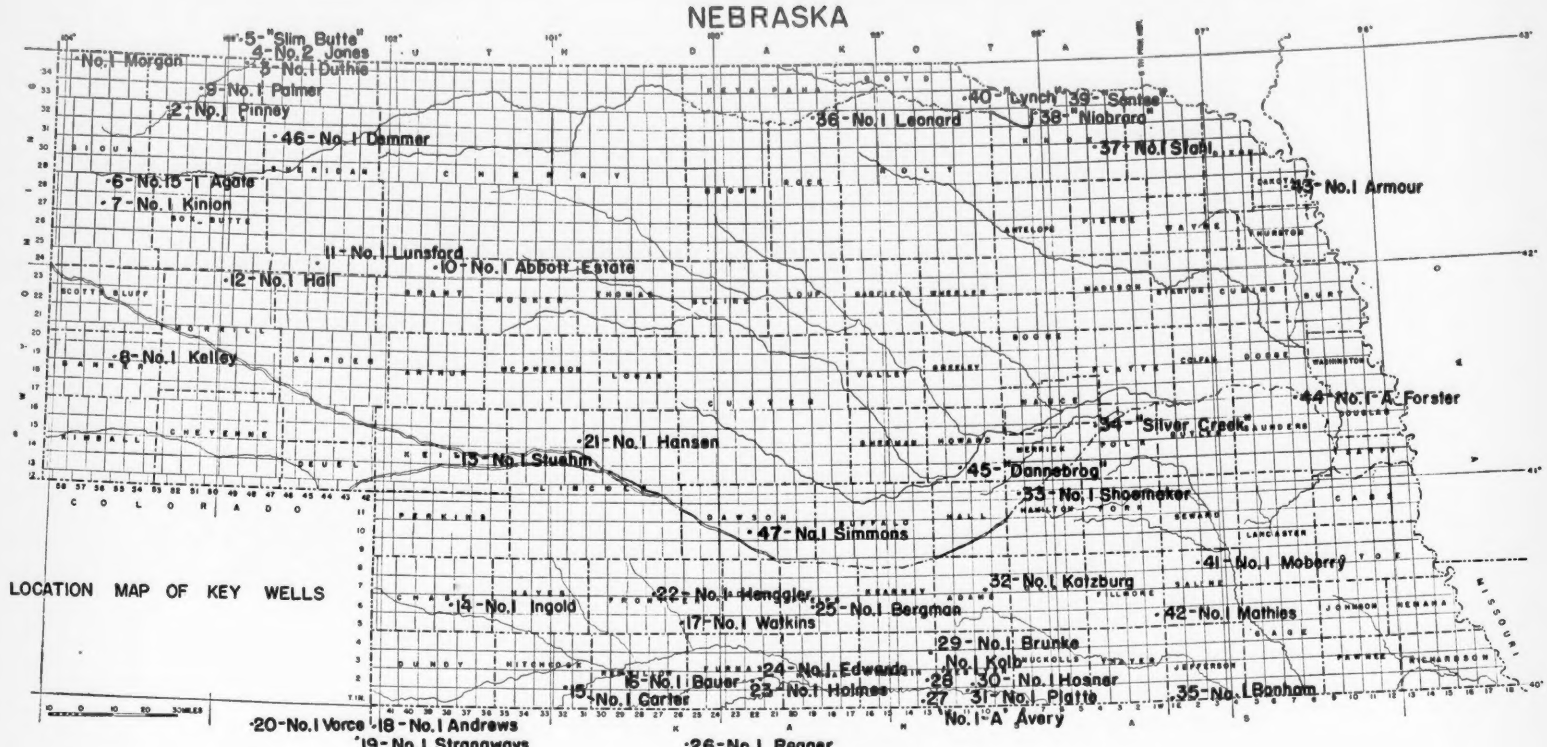

FIG. 1.—Well location map.

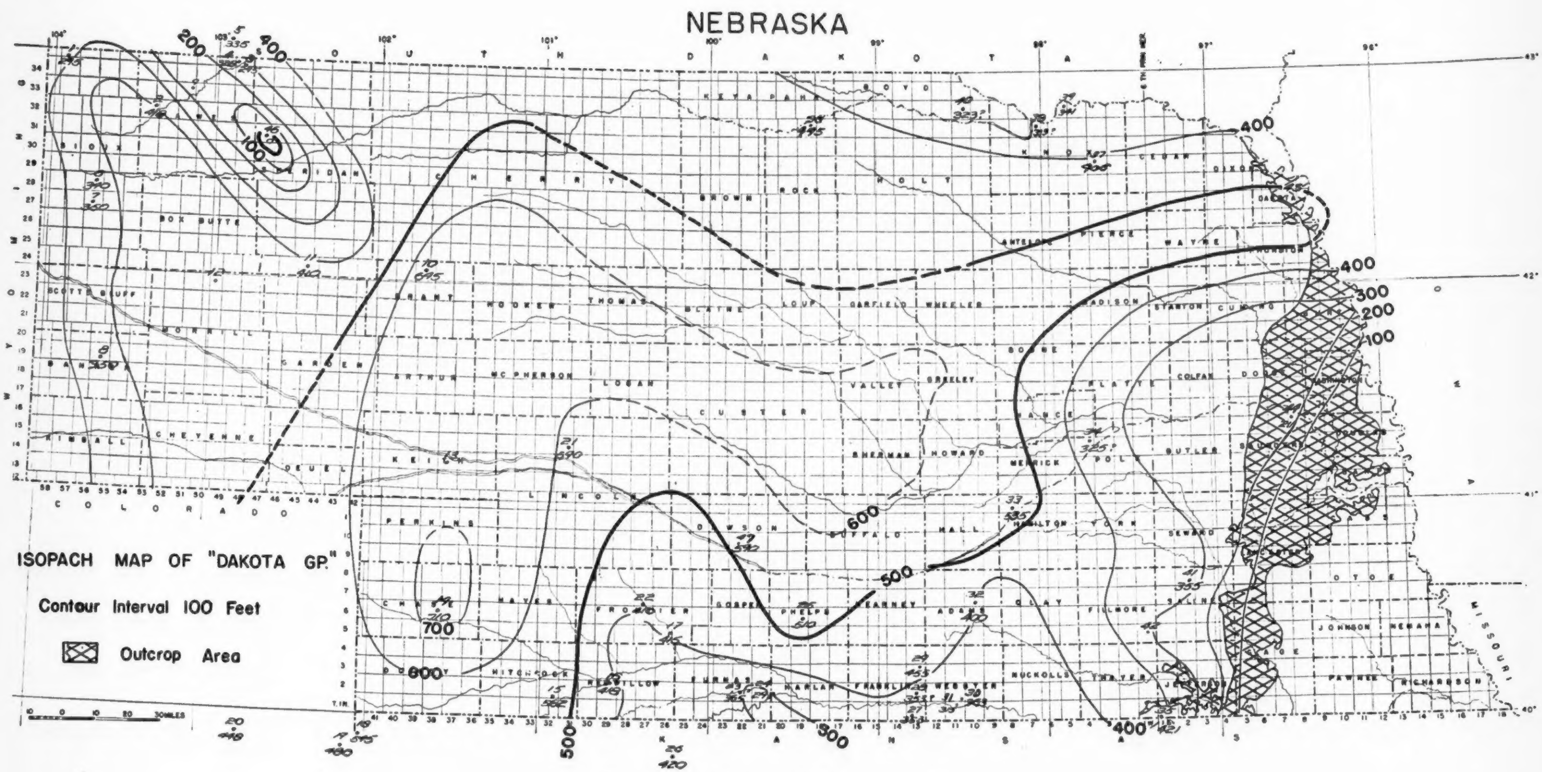

FIG. 2.—Isopach map of "Dakota group."

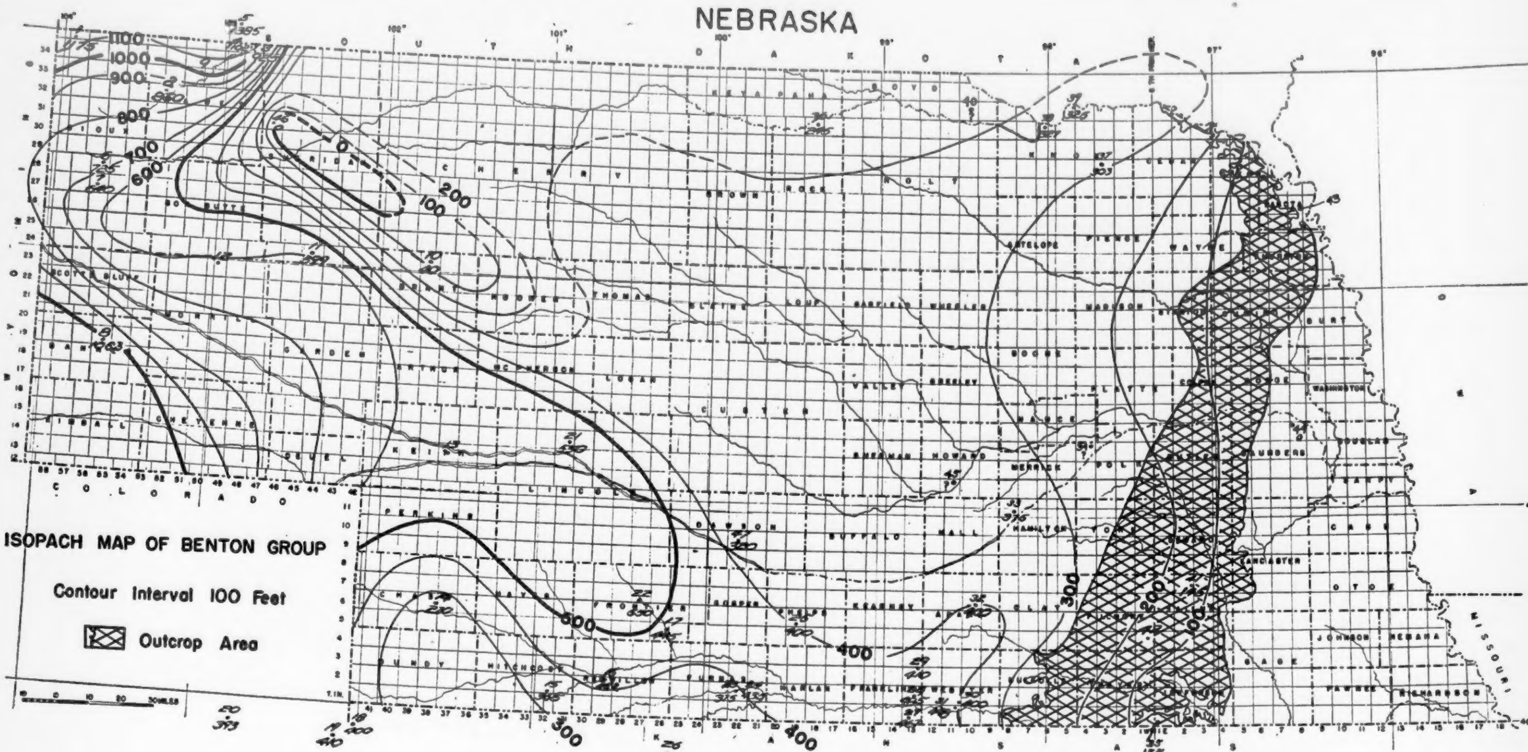

Fig. 3.—Isopach map of Benton group.

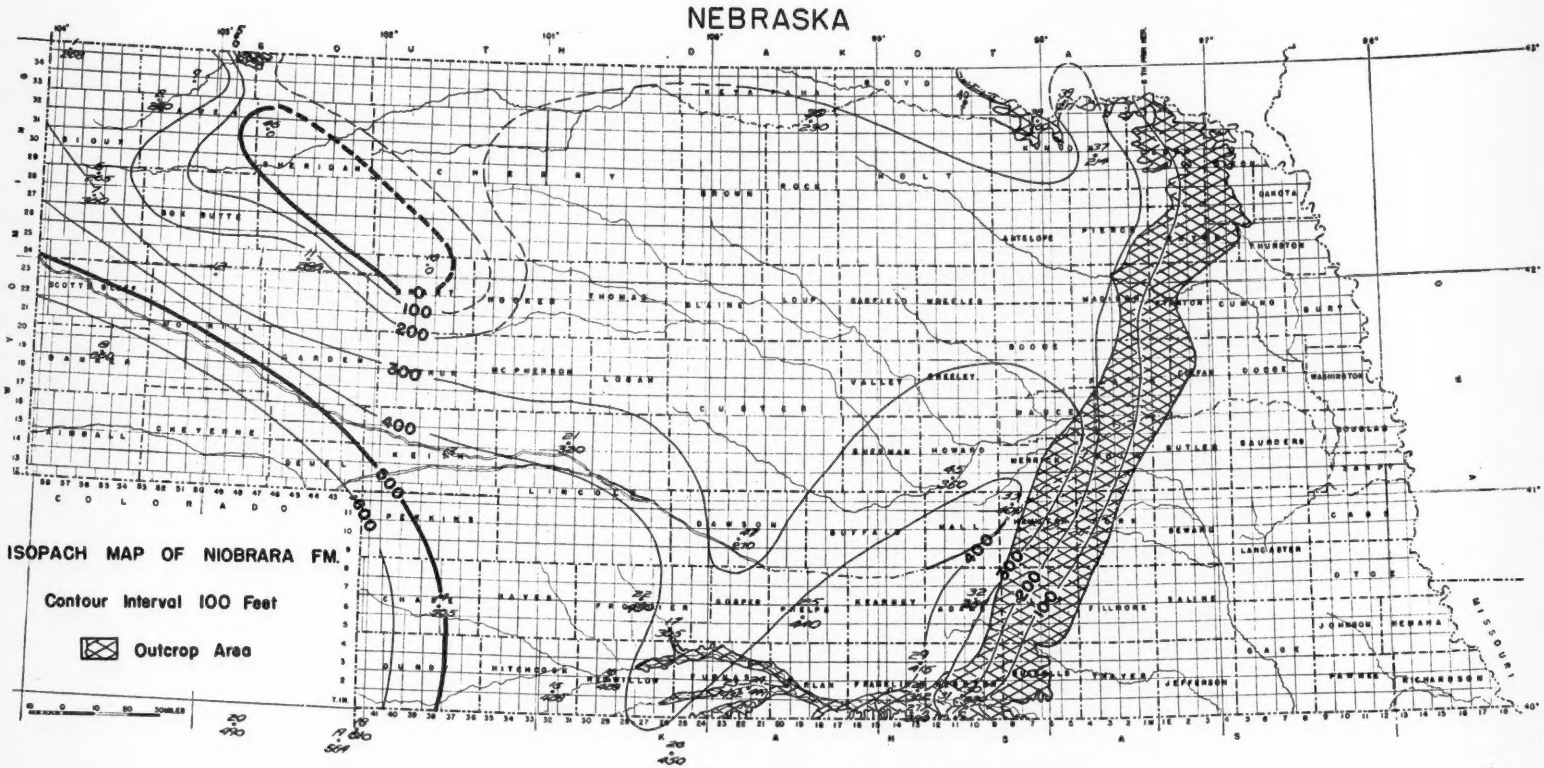

FIG. 4.—Isopach map of Niobrara formation.

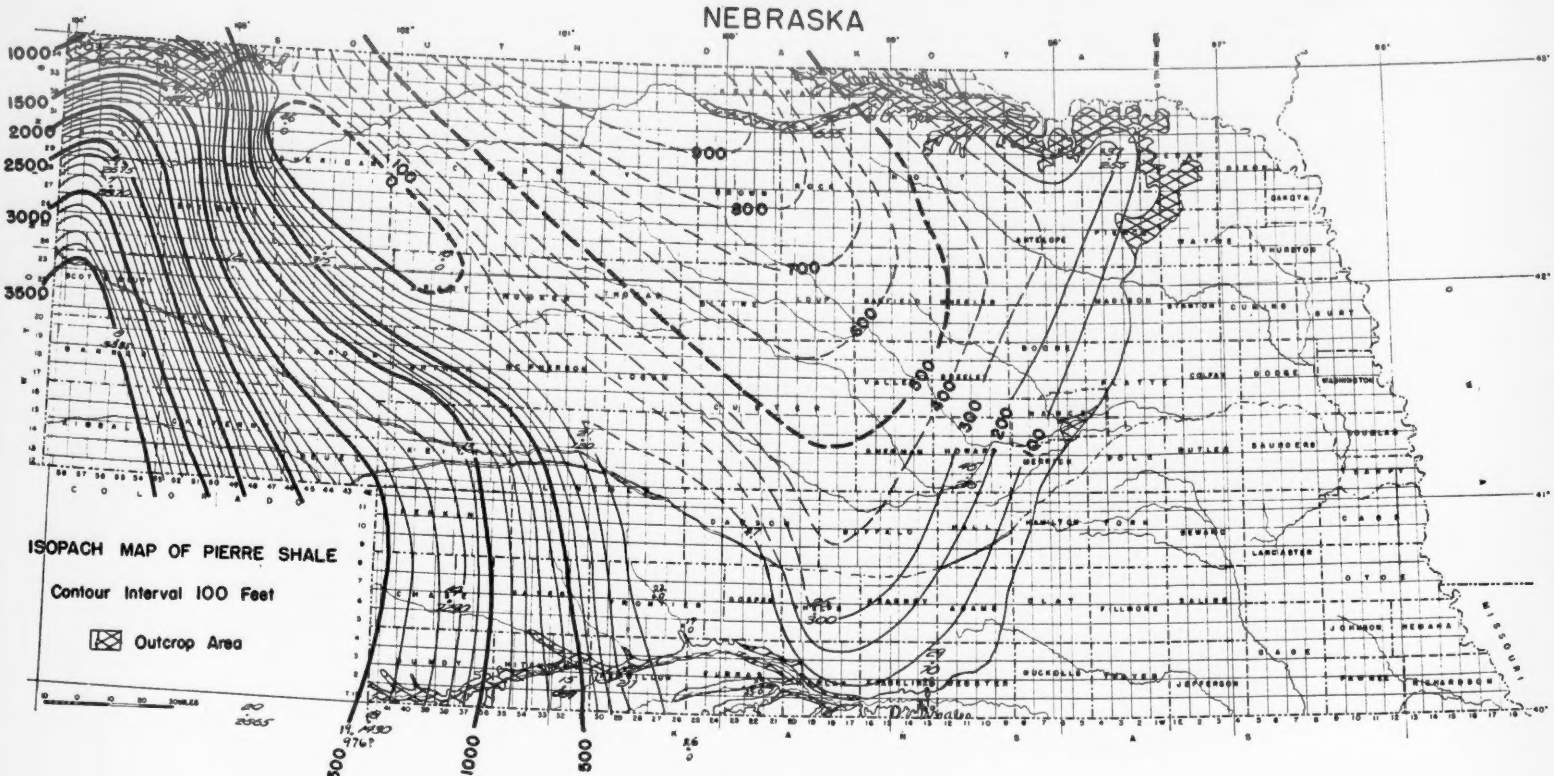

FIG. 5.—Isopach map of Pierre shale.

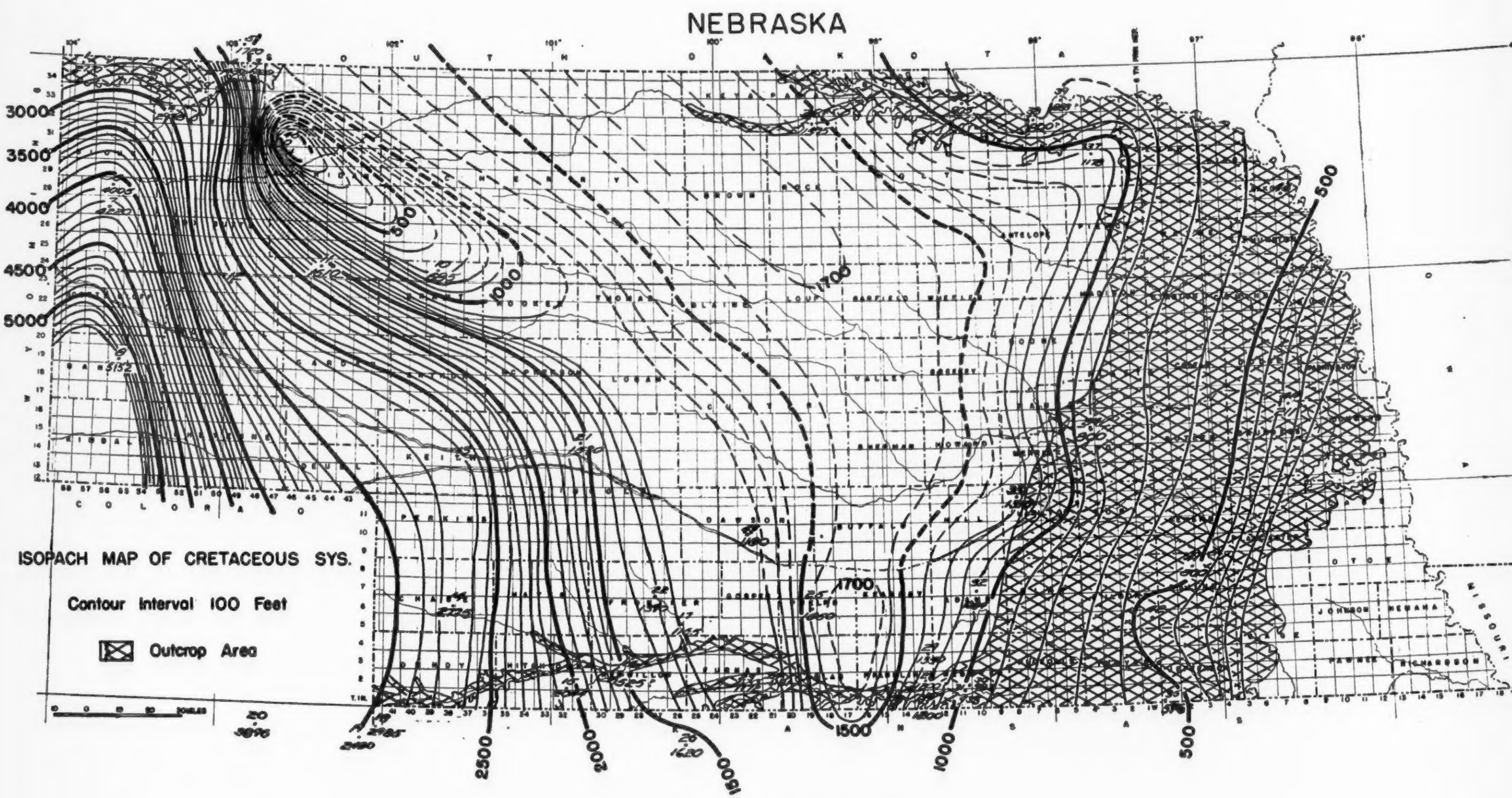

Fig. 6.—Isopach map of Cretaceous system.

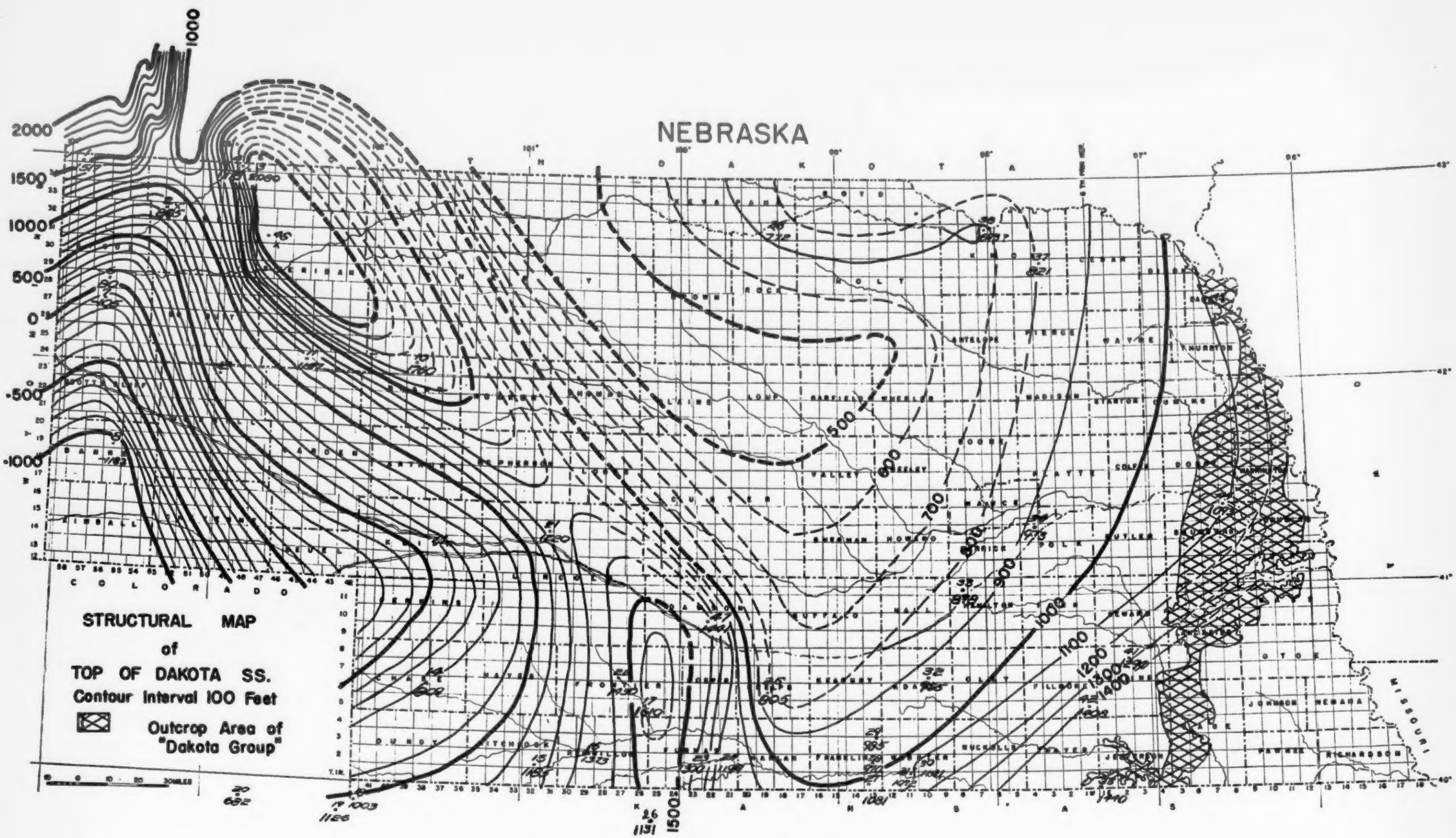

FIG. 7.—Structural map of top of Dakota sandstone.

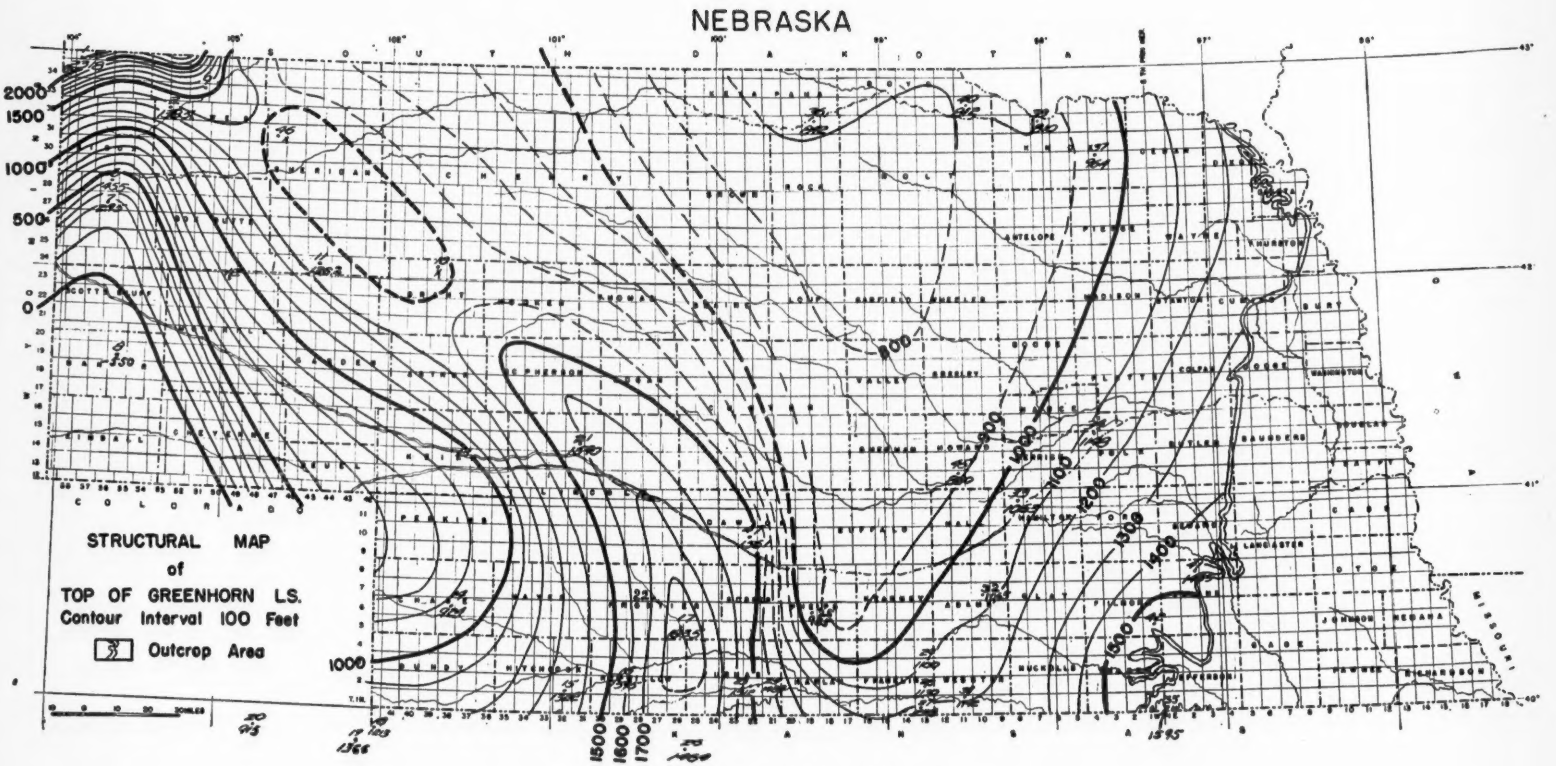

FIG. 8.—Structural map of top of Greenhorn limestone.

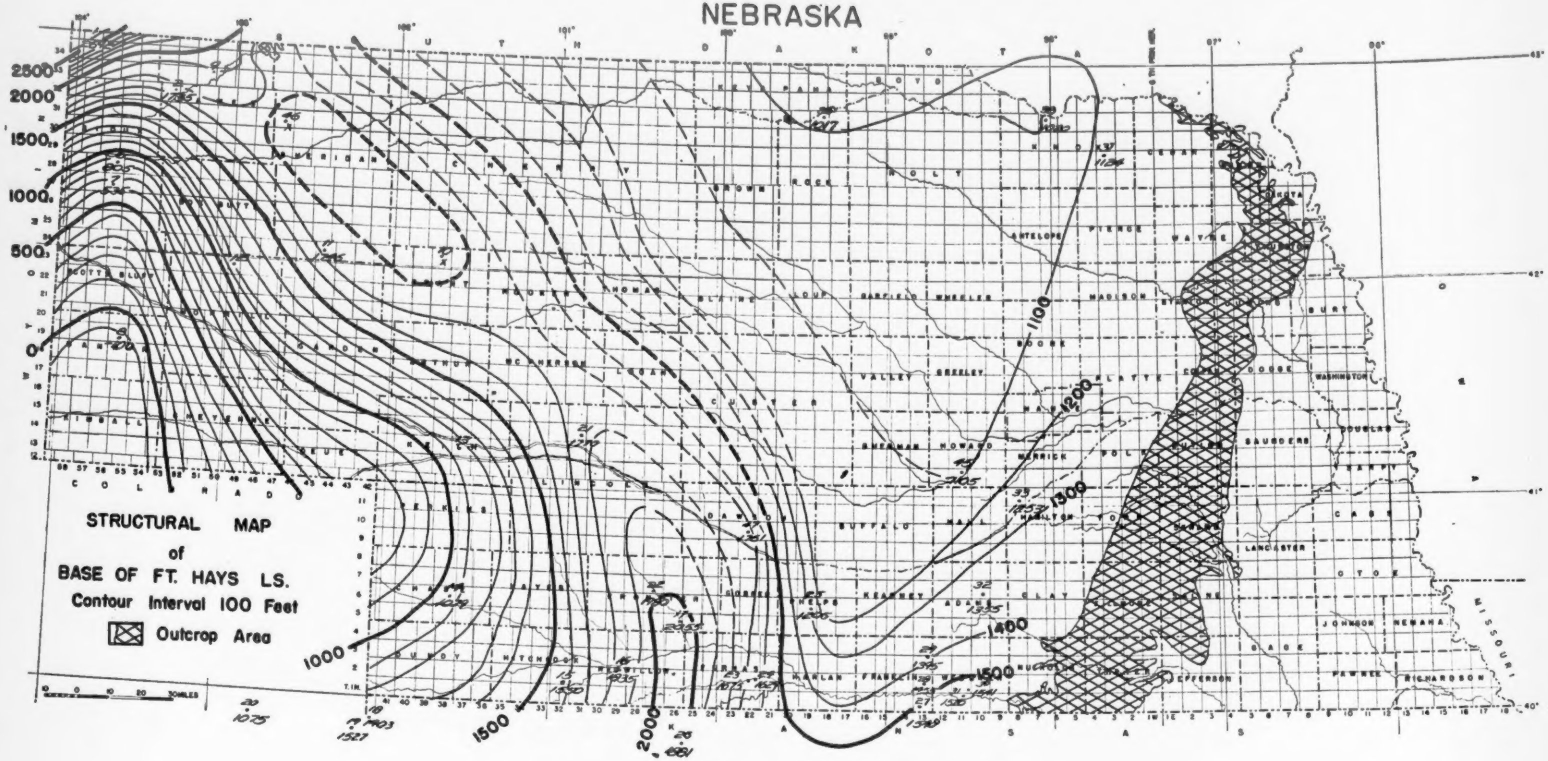

FIG. 9.—Structural map of base of Fort Hayes limestone.

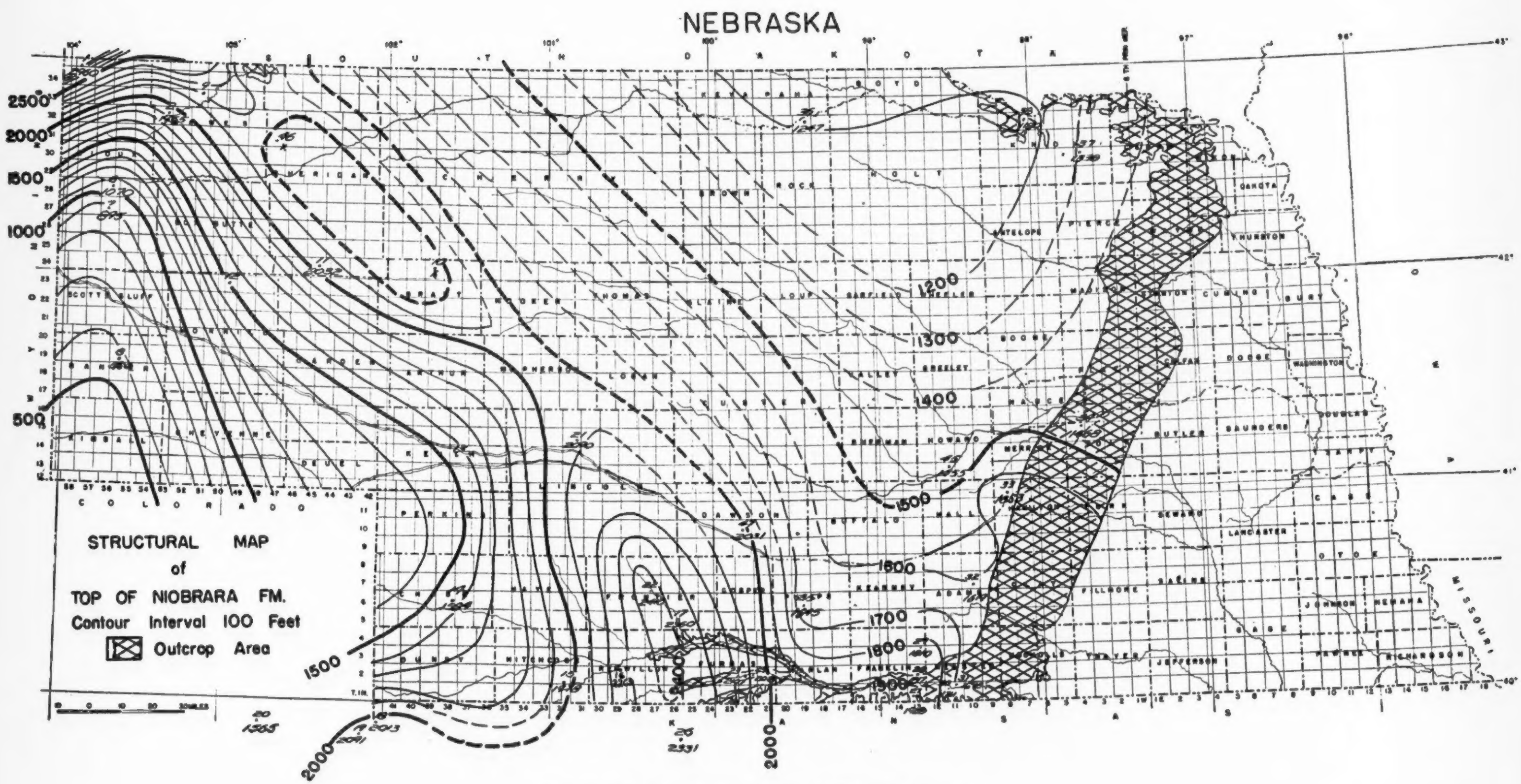

Fig. 10.—Structural map of top of Niobrara formation.

In eastern Nebraska, the group is subdivided into the Dakota sandstone (upper part), consisting of two sandstone beds with interbedded shale, the Fuson shale (middle), and the Lakota sandstone (lower). In northwestern Nebraska, the beds which apparently are equivalent to all or part of the Dakota sandstone elsewhere are commonly subdivided into an upper sandstone (Newcastle or Muddy), a middle shale (Skull Creek shale), and a lower sandstone (Fall River).

The Fall River sandstone is light to dark gray sandstone with interfingering beds of gray shale. The middle shale (Skull Creek equivalent) of the Dakota sandstone is for the most part gray and generally sandy. The upper sandstone (Newcastle or Muddy equivalent—?) generally is yellowish to brownish in color and fine-grained. It commonly contains more or less clay-ironstone concretionary material.

The Fuson shale in outcrops is ordinarily red or vari-colored, with some thin sandstone lenses, but this shale is largely dark gray to black in the subsurface of the deeper parts of the Cretaceous basin. The Lakota sandstone is fine- to coarse-grained, with some dark gray to light-colored shale partings. It ranges in color from yellowish (and ferruginous with clay-ironstone) to almost pure white.

DISCUSSION OF RESULTS

The isopach maps do not necessarily show the true extent of land and sea areas during the Cretaceous, since they represent present thicknesses only and not thicknesses as originally deposited. The structural maps are based on scattered data which do not reflect local structures to any degree but do indicate general structural relationships. These maps are to be interpreted as the resultant of all deformation subsequent to deposition, including compaction and settling effects, plus original slopes of deposition. Because of these conditions, it is difficult to determine the time of any specific movement from these data alone.

The absence of Cretaceous in the Ohio-Demmer well at Hay Springs (Jones, 1940, p. 141), is believed to be due to post-Cretaceous pre-Tertiary erosion along the crest of the Chadron-Cambridge axis. This condition modifies Ver Wiebe's isopach map of the Cretaceous (1933) on which the Cretaceous is shown as a continuous sheet of sediments in this particular region.

Deposition during "Dakota group" time was probably more or less continuous and extensive throughout the greater part of Nebraska, with the maximum thickness attained in the central part of the state. The absence of the "Dakota group" in the Ohio-Demmer well does not necessarily indicate non-deposition during "Dakota group" time. Instead, the absence of these beds is more probably due to erosion in post-"Dakota" or post-Cretaceous time.

Deposition of the Benton group seems to have been continuous and extensive over much of Nebraska. The thick development of the Benton group in the area of the Chadron anticline, as revealed by the thickness of 925 feet encountered in the Duthie well, and the extensive development over the Cambridge anticline, where a thickness of 445 feet is reported in the Watkins well, explains the lack of

conformity between the Benton group isopach map and the structure maps. It is therefore probable that the absence of the Benton group at the location of the Ohio-Demmer well is the result of erosion during post-Benton time.

The Niobrara sediments attained their greatest thickness in a basin covering most of southwestern Nebraska. The absence of the Niobrara formation in the Abbott No. 1, Ohio-Demmer, Duthie, and Jones No. 2 wells is probably the result of post-Cretaceous erosion and not of non-deposition. This suggests but does not prove that the north part of the Cambridge-Chadron axial structure was a positive element during part of Niobrara time, and that the north part of this structure experienced movement earlier than at Cambridge. It should be noted that the absence of the Niobrara also could have resulted entirely from post-Niobrara or post-Cretaceous erosion.

The isopach map of the Pierre shale reveals a definite relationship to the structure maps. It indicates that the region over the north and central parts of the Chadron-Cambridge axial "high" was subjected to extensive post-Cretaceous erosion. Pierre thicknesses are great southwest of this axis where a maximum drilled thickness of 3,540 feet was penetrated in the Harrisburg well. Deposition east of this axis was either in a large shallow basin, or much of the original Pierre thickness has been removed by post-Cretaceous erosion, because the maximum drilled thickness is only 655 feet (Bassett well).

The conformity of the isopach map of the Cretaceous system with the structure maps indicates the great thickness and wide extent of Pierre deposition. Furthermore, if only an isopach study of the Cretaceous system as a whole had been made, the true relationship of the thicknesses to the structure of the "Dakota group," Benton group, and Niobrara formation could not have been detected. Hence, the isopach map of the Cretaceous system can not be interpreted as an indication of relationship of structure to thickness.

CONCLUSIONS

The structure maps reveal the close relationship and probable continuity of the Chadron anticline and the Cambridge anticline as an axis trending from northwest to southeast across the state. These "highs" are shown prominently on the four structure maps. The "lows" are east and west of this axial "high." The deepest basin is on the west in the extreme southwest part of the state. East of the axial "high" the basin covers a larger area in Nebraska and is not as deep as the one west of it. The influence of the Sioux Falls "high" in southeastern South Dakota is evident in the structure of northeast Nebraska.

The isopach map of the "Dakota group" suggests the presence of a large basin throughout central Nebraska during the time that this group was deposited. This is shown by the thick development of the "Dakota group" in central Nebraska. The narrow strip of great thickness developed in the "Dakota group," extending from central Nebraska to the north-central part of eastern Nebraska suggests a trough between the Sioux Falls "high" and a land area southeast. It may also

suggest that the source materials for the "Dakota group" came in part from both these areas.

The absence of the Niobrara formation over the top of the north part of this Chadron-Cambridge axis suggests, as already noted, that some movement very likely took place in the northern part of this structure at an earlier date than in the south part, the north part probably beginning its movement in Niobrara time and the southern extension rising during Pierre time.

From the similarity of the Pierre isopach map to the structure maps, it may be surmised that considerable movement of this axis took place near the close of (or subsequent to) Pierre time. The thickest section of the Pierre is over the "low" shown on the structural map of the top of the Niobrara formation. Likewise, the Pierre shale is thin or absent over the axial "high." This positive element probably existed and exercised some control over sedimentation during much of Pierre time, with deposition taking place in a broad shallow basin on the east and in a relatively deep and narrow basin on the west.

Much of Nebraska has as yet not been thoroughly tested for oil or gas, and water wells are not sufficiently deep to contribute information on Cretaceous thicknesses, especially in the central part of the state. In such places, therefore, where information was lacking, dashed lines were used to suggest the probable relationships. It is hoped that with further drilling these questionable areas will be eliminated and a more accurate picture of the subsurface structure and Cretaceous stratigraphy of Nebraska may become available.

Any far-reaching interpretations based on these maps probably would be premature at this time; and, for this reason, the maps are presented without elaborate conclusions. They do, however, portray a synthesis of much factual information about the subsurface geology of the state, and it is hoped that they may be of value in understanding the structure and stratigraphy of the Cretaceous system in Nebraska.

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VOL. 26, NO. 9 (SEPTEMBER, 1942), PP. 1537-1541

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available, for loan, to members and associates.

FIELD GEOLOGY, BY FREDERIC H. LAHEE

REVIEW BY WALLACE E. PRATT[1]
New York, N. Y.

Field Geology, by Frederic H. Lahee. 4th ed. (1942). 828 pp. plus table of contents and index. McGraw-Hill Book Company, Inc., New York, N. Y. Price, $5.00, postpaid.

The current war-time search for strategic minerals throughout the Western Hemisphere accentuates the timeliness of a new edition of *Field Geology*.

> As populations outstrip national agricultural resources, industrialization furnishes the only means of maintaining or improving standards of living. Industrialization requires minerals in ever greater volume. In no country are all the necessary minerals indigenous. As world industry grows, as grow it will, the problem of raw material supply, already serious, will become even more acute, and success in securing supplies will determine the future ranking of nations in industrial and military power.[2]

Lahee's hand-book has long been standard for field geologists. Petroleum geologists—fellow-workers with the author—have been inclined to think of *Field Geology* as embracing only the subject of petroleum geology. But the scope of the book is far broader than any single field of inquiry, as instructors who have used it as a textbook for courses in general geology will testify. The first twelve chapters—roughly, half the book—are devoted to geologic phenomena in general, including mineral deposits, igneous and metamorphic rocks, vein formation, metamorphism, physiography, and land sculpture, as well as the nature of sedimentary processes, the character of sedimentary rocks, their form, sequence, and structure. The remaining half of the book is given over to field methods of observation, survey, recordation, and presentation. Recognizing that the problems of the field geologist can rarely be satisfactorily solved through surface studies only, the author devotes a solid chapter to subsurface geology. Modes of geologic illustration are also treated at full chapter length. Airplane mapping and geophysical surveying are presented in considerable detail as indispensable modern aids to geologic interpretation. Color photography is emphasized as a superior method of recording field observations.

Field Geology has expanded in scope and utility through successive editions as its author advanced in his profession. The first edition, published in 1916, is stamped with the imprint of the well trained, earnest, and painstaking young professor who compiled it, largely from the available records of the observations of other workers. But Fred Lahee, in his own right, has always possessed great capacity for observing and classifying, as well as for recording. As he became more active himself in the rôle of field geologist, material for his hand-book mounted out of his own experience. Every incident in his daily routine became grist to his mill. Now he has at his command the total array of facts that an insatiable curiosity, active through a long, distinguished career as a professional geologist, has succeeded in uncovering, all catalogued, interpreted, and woven into a background of experience, against which the problems of the field geologist are ranged for study. The author has a natural bent for systematizing knowledge, and his talent is reflected on the pages of his book. Thus his pioneer studies of the faulted oil reservoirs, revealed by the discoveries at Mexia and Powell in the early 1920's, were promptly trans-

[1] Director, Standard Oil Company (New Jersey). Manuscript received, July 28, 1942.

[2] C. K. Leith, *Strategic Minerals in War and Peace*, Geol. Soc. America, New York (1940).

lated into original material for inclusion in *Field Geology*. In the same manner, the new techniques of the last ten years, from whatever geologic research they emanated—mass movements, mineral orientation, electric well logging, or radioactivity as a criterion for subsurface correlation—all find a place in the fourth edition.

The illustrations in *Field Geology* are excellent. The subjects are selected with discrimination and the drawings are executed with skill. Despite obvious care in preparation, however, a few of the line diagrams are faulty; text Figure 246 is blurred, and from Figure 259 the reference letter "a" has been omitted. Similarly, an occasional slip can be detected in the attempt to bring the latest edition fully up to date. For example, the first (1916) edition correctly stated: "the view [on the origin of the salt domes] most commonly held in this country until a few years ago was that the salt was deposited from ascending waters," but the same statement has lost its validity in 1942, some twenty years after the practical abandonment of this mistaken pioneer theory.

Field Geology is a comprehensive work, edited with meticulous care. The table of contents runs through twenty pages, the index through more than thirty. There are voluminous appendices of appropriate data, including a scheme for the identification of clastic sedimentary rocks, and a useful bibliography of original sources.

The geologic profession is fortunate to have access at this time to a new edition of a reference work of the character of *Field Geology*.

HYDROLOGY, EDITED BY OSCAR E. MEINZER

REVIEW BY FREDERIC H. LAHEE[1]
Dallas, Texas

Hydrology, edited by Oscar E. Meinzer, geologist in charge, Division of Ground Water Geological Survey, United States Department of the Interior, Washington, D. C. 712 pp., 6×9 inches, many illustrations, charts, and tables. McGraw-Hill Book Company, Inc., New York and London (1942). Price, $7.50.

Hydrology, edited by Oscar E. Meinzer and published by the McGraw-Hill Book Company, is the most up-to-date and the most complete treatment of the subject covered by the title. Its various subtopics are contributed by 24 specialists, and these contributions have been carefully and successfully compiled in a well integrated whole. The scope of this excellent book may best be outlined by quoting from the Introduction.

> The central concept in the science of hydrology is the so-called hydrologic cycle—a convenient term to denote the circulation of the water from the sea, through the atmosphere, to the land; and thence, with numerous delays, back to the sea by overland and subterranean routes, and in part, by way of the atmosphere; also the many short circuits of the water that is returned to the atmosphere without reaching the sea.
>
> The science of hydrology is especially concerned with the second phase of this cycle—that is, with the water in its course from the time it is precipitated upon the land until it is discharged into the sea or returned to the atmosphere. It involves the measurement of the quantities and rates of movement of water at all times and at every stage of its course—rain and snow gaging to determine both the quantities and rates of rainfall and snowfall in all parts of the earth; snow surveying to determine the quantities of water stored as snow on the surface and the rates of its accumulation and disappearance; observations of the advance and retreat of glaciers and surveys of the glaciers to determine the quantities of water that they contain and their rates of gain or loss; the gaging of streams, both large and small, to obtain continuous records of their flow at many points and during long periods; the gaging of lake levels to compute the gains and losses in their storage; measurements of the rates and quantities of infiltration into the soil and the movement of the soil moisture; periodic or continuous measurements of the water levels in wells to compute the gains and losses in underground storage; determinations of the permeability of the water-bearing formations and of the rates at which they are transmitting water; measurements of the discharge of springs and of total

[1] Chief geologist, Sun Oil Company. Manuscript received, August 6, 1942.

effluent seepage; determinations of the loads of dissolved and suspended matter which the waters contain in every position and the rates at which they carry it from one position to another; the quantities of water lost by evaporation and the rates of loss from the lakes, ponds, swamps, and streams, from the land surface, from objects on the surface and from the soil, and the quantities lost by transpiration from the leaves of growing plants, including native and cultivated trees, shrubs, and herbs. Hydrology is concerned with the development of accurate and feasible methods of making these measurements of diverse kinds, and with the accumulation and compilation of the great mass of resulting quantitative data. Finally, it is concerned with the great task of making rigorous studies of all the base data to determine the principles and laws involved in the occurrence, movement, and work of the waters in the hydrologic cycle.

For practical reasons, the subject of oceanography (oceanology) is omitted, as also are certain other special subjects pertaining to water in its more intimate relations to geology. In its restricted sense, the science of hydrology is concerned essentially with the waters of the land—the atmospheric water so far as precipitation and evaporation are concerned; the water occurring on the land surface, as snow or ice or as liquid water that is flowing or impounded; and the water occurring below the surface in the interstices of the soil and the underlying rocks.

In general the many phases of this comprehensive subject are well discussed. However, there is room for expansion on some topics. For instance, the very important subject of engineering problems of limestone terranes, of paramount significance in Florida, is too briefly treated (p. 674).

From the quoted outline of the scope of hydrology, it is obvious that only a small part of the science is of immediate concern to petroleum geologists. The chapter dealing with ground water, by Dr. Meinzer, touches upon porosity and permeability of rocks, connate water, the movement of ground water, *et cetera*. However, there appears to be no discussion of certain phases of the subject of ground water in its associations with oil. For instance, much has been learned about methods of pumping oil-field waters back into the reservoir sands, and much has been learned of the importance of expansion of deep ground water as a driving force where a reservoir has been opened to production of its fluid content by drilling; but treatment of these topics we fail to find. The reviewer has long felt the need of coöperative study between the hydrologists, as usually understood, and the petroleum engineers, on this overlapping ground of mutual interest. We make this suggestion not so much as a criticism of the present text, which is excellent, but merely as an idea to be considered for later enlargement of this book.

There are two minor criticisms which might be offered. The index could be considerably expanded with resulting increase in its usefulness. The weight of the paper seems to be excessive, but perhaps this is just one of those unfortunate results of the war.

Excepting these few slightly adverse comments, we take pleasure in highly commending this treatise. It should be on the bookshelves of all those who are concerned with any of the numerous branches of hydrology.

RECENT PUBLICATIONS

ALABAMA

*"Geology and Oil in Alabama," by Stewart J. Lloyd. *Oil*, Vol. 2, No. 5 (810 Union Street, New Orleans, July, 1942), pp. 11–12; 3 photographs and map.

ARGENTINA

*"Geology of the Territory of Pampa West of the Chadi-Leuvu River," by Jose Maria Sobral. *Y.P.F. Bol. Inf. Petrol.*, Vol. 19, No. 212 (Buenos Aires, April, 1942), pp. 33–80; 38 figs., 2 maps. In Spanish.

AUSTRALIA

**Reports of the Great Barrier Reef Committee*, Vol. 5 (April 30, 1942). Reprints from the University of Queensland Department of Geology, Orient Line Building, 113 Eagle Street, Brisbane, Australia. 122 pp., 12 pls. Paper cover. 6.125×9.625 inches. Contains 3 articles: (1) "Great Barrier Reef Bores, 1926 and 1937.—Descriptions, Analyses, and Interpretations," by H. C. Richards and Dorothy Hill, pp. 1–111, with 8 pls. of photomicrographs and 2 sample-composition charts; (2) "A Report on Samples Obtained by the Boring at Heron Island, Great Barrier Reef, Australia," by Joseph A. Cushman, pp. 112–19, with 2 pls. of Foraminifera; (3) "Report of Molluscan Content of Heron Island Reef Boring Samples," by Tom Iredale, pp. 120–22.

CALIFORNIA

*"Eocene Radiolarian Faunas from the Mt. Diablo Area, California," by Bruce L. Clark and Arthur S. Campbell. *Geol. Soc. America Spec. Paper 39* (New York, July 25, 1942). 112 pp., 9 pls., 5 figs.

CANADA

*"Marble Mountain Map-Area, Alberta," by H. H. Beach. *Canada Geol. Survey Paper 42-3* (Ottawa, 1942). 15 pp. Paper cover. 6.5×9.75 inches. Map sheet approximately 28×44.5 inches. Paper, blue-line print. Scale, 1 inch = 2 miles. Topographic contour interval, 100 feet. Shows Paleozoic, Mesozoic, and Cenozoic, with 3 longitudinal structure sections. Price, $0.10.

*"Preliminary Map, Cypress Lake, Saskatchewan," by G. M. Furnival. *Ibid.*, *Paper 42-5* (1942). Paper sheet, 28×40.5 inches. Scale, 1 inch = 2 miles. Mesozoic and Cenozoic. Price, $0.10.

*"Preliminary Map, Bassano, Alberta," by J. S. Stewart, *Ibid.*, *Paper 42-8* (1942). 4 mim. pp. Map sheet, blue-line print, approximately 16×20.75 inches. Scale, 1 inch = 4 miles. Upper Cretaceous and Tertiary. Price, $0.10.

"Research Touches the North," by S. C. Ells. *Canadian Geogr. Jour.*, Vol. 24, No. 6 (2151 Ontario Street, Montreal, June, 1942), pp. 257–67; sketch map of exposures of bituminous sand area in Alberta, 8 pen-and-ink illustrations by the author. "Commercial potentialities of Alberta's bituminous sands—to meet Allied oil needs for times of peace and war." Annual subscription to the *Journal* (membership in Canadian Geographical Society): $3.00, postpaid in Canada; $3.50, in United States, Central and South America; $4.00, other countries; single copies, $0.35.

COLOMBIA

*"Geology of the Department of Magdalena," by Victor Oppenheim. *Revista Acad. Colombiana Ciencias Exactas, Fisicas y Naturales*, Vol. 4, Nos. 15–16 (Bogota, December, 1941), pp. 380–384; 12 photographs, geological map in colors. In Spanish.

GENERAL

"Petroleum Development and Technology, 1942," by the Petroleum Division. *Trans. A.I.M.E.*, Vol. 146 (New York, 1942). 565 pp. Papers and discussions presented before the Division meetings of the Institute held in New York, Dallas, and Los Angeles in 1941, and the petroleum statistical reports for 1941. Cloth. 6×9 inches. Price, $5.00.

"Geology and Biology of North Atlantic Deep-Sea Cores between Newfoundland and Ireland, Part 9, Selenium Content and Chemical Analyses," by Glen Edgington and H. C. Byers. *U. S. Geol. Survey Prof. Paper 196-F* (June, 1942), pp. I-XV, 151–155, Pls. 1–2, Fig. 1. Supt. Documents, Govt. Printing Office, Washington, D. C. Price $0.15.

*"Determination of Oil-Well Capacities from Liquid-Level Data," by Charles C. Rodd. *A.I.M.E. Petrol. Tech.*, Vol. 5, No. 4 (New York, July, 1942). 9 pp., 3 figs. *Tech. Pub. 1475.*

*"Permeability as a Function of the Size Parameters of Unconsolidated Sand," by W. C. Krumbein and G. D. Monk. *Ibid.*, 11 pp., 5 figs. *Tech. Pub. 1492.*

Aerophotography and Aerosurveying, by J. W. Bagley. 324 pp., illus., diagrams, charts, tables. 9.5×6 inches. Cloth. McGraw-Hill Book Company, New York (1941). Price, $3.50.

**Oil and Petroleum Year Book 1942*, compiled by Walter E. Skinner. "The international Standard Reference book on the oil industry of the world." 290 pp. Demy 8vo. Red cloth. Walter E. Skinner, 20 Copthall Avenue, London, E. C. 2. Price, abroad, 11 s., net.

LOUISIANA

*"Geophysical History of Darrow Dome, Ascension Parish, Louisiana," by J. Brian Eby and T. I. Harkins. *A.I.M.E., Petrol. Tech.*, Vol. 5, No. 4 (New York, July, 1942). 8 pp., 5 figs. *Tech. Pub. 1495.*

MEXICO

*"Reservas Petroleras," by Manuel Rodriguez de Aguilar. *Ingenieria*, Vol. 16, No. 4 (Mexico, D. F., April, 1942), pp. 138–48). Petroleum possibilities of Mexico. In Spanish.

*"Mexican Activity in Poza Rica Oil Field, Veracruz," by Juan Maxemin. *Bol. Minas y Petroleo*, Vol. 13, No. 4 (Mexico, D. F., January-March, 1942), pp. 122–29; 5 photographs and a folded location map of the field. "Efficient drilling." In Spanish.

TURKEY

*"Preliminary Compilation of the Stratigraphy, Structural Features and Oil Possibilities of Southeastern Turkey and Comparison with Neighboring Areas," by S. W. Tromp. *Pub. Min. Research Inst. Turkey Brief Communication 4*, Ser. A (Ankara, 1941). 34 pp.: 1–18 in Turkish; 19–34 in English; 6 pls.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

* *Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 12, No. 2 (August, 1942).

"Accumulation of Diatomaceous Deposits," by Paul S. Conger.

"Dolomitic Mottling in the Platteville Limestone," by Robert H. Griffin.

"Sedimentary Petrologic Provinces of the Northern Gulf of Mexico," by August Goldstein, Jr.

"Gravity Versus Centrifuge Separation of Heavy Minerals from Sand," by Gordon Rittenhouse and W. E. Bertholf, Jr.

"Petrographic Microscope Slides of Detrital Mineral Grains," by Paul Herbert, Jr.

"Rate at Which Foraminifera Are Contributed to Marine Sediments," by Earl H. Myers.

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||Anderson, Kenneth Clyde, 3701 Benton Blvd., Kansas City, Mo.
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Bayles, Robert Ellery, Peoples Nat. Gas Co., 545 William Penn Way, Pittsburgh, Pa.
Bazhaw, Willis Oliver, Petty Geophysical Eng. Co., 1004 Hunt Bldg., Tulsa, Okla.
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Bower, Thomas Henry, Trinidad Leaseholds, Ltd., Fyzabad, Trinidad, B.W.I.
||Breedlove, Robert Leeroy, Arkansas Fuel Oil Co., 1704 Milam Bldg., San Antonio, Tex.
Brehm, Ralph C., 1739 Bolsover Rd., Houston, Tex.
Brown, Glen Francis, U. S. Geol. Survey, Box 653, University, Miss.
Brown, Hart, Brown Geophysical Co., Box 6005, Houston, Tex.
||Brown, Orman Pearson, Shell Oil Co., Inc., Box 476, Centralia, Ill.
||Buehler, Karl Martin, Gulf Oil Corp., 1107 Union Natl. Bank Bldg., Wichita, Kans.
Busch, Daniel Adolph, 1132 C. L., Univ. of Pittsburgh, Pittsburgh, Pa.
Carlson, Stanley A., Richfield Oil Corp., Box 1710, Bakersfield, Calif.
||Caver, William Frank, Box 187, Kilgore, Tex.
Cooke, William Forester, Jr., Sun Oil Co., Beaumont, Tex.
Crockett, Harry Lee, 326 E. Sixth St., Edmond, Okla.
||Crosbie, J. M., Shell Oil Co., Inc., 641 M. & M. Bldg., Houston, Tex.
||Damon, Frederic Thomas, 1312 Dewey, Bartlesville, Okla.
||Darling, Jack N., Hogg Oil Co., Houston, Tex.
||Davis, Donald M., United Geophysical Co., 1255 E. Green St., Pasadena, Calif.
||Davis, Field M., Monday Oil Co., 2802 Smith-Young Tower, San Antonio, Tex.
||Davis, Gene O., Skelly Oil Co., 510 Petroleum Bldg., Wichita, Kans.
||Davis, Lon, Jr., Floydada, Tex.
||Decker, Willis Mansfield, Goddard, Kans.
de Koch, William G., 1033 Petroleum Bldg., Vermilion, Alta., Canada
||Diemer, Raymond Adams, Stanolind Oil & Gas Co., Box 1540, Midland, Tex.
Dilger, Raymond Joseph, Mountain Fuel Supply Co., Rock Springs, Wyo.
||Doshier, Achille W., 827 Caroline, Amarillo, Tex.
Dryden, Lincoln, Bryn Mawr College, Bryn Mawr, Pa.
Dudley, Raymond W., Pure Oil Co., Box 2107, Fort Worth, Tex.
Dyk, Robert, Western Geophysical Co., Anglo Bank Bldg., Hanford, Calif.
Estergren, E. F., Algord Oil Co., Box 1106, Dallas, Tex.
||Fender, Hollis Blair, Dept. of Soil Investigation, Wabash River Ordnance Works, Bloomington, Ind.
Fischer, LeRoy Fred, Gulf Refg. Co., Houston, Tex.
Fitting, Ralph U., Jr., Shell Oil Co., Inc., Midland, Tex.
||Foster, Paul Woodward, Atlantic Refg. Co., 1640 Mellie Esperson Bldg., Houston, Tex.
||Fowler, Henry Florey, Gulf Refg. Co., Shreveport, La.
Franklin, Donald W., 302nd (C.A.) Bar. Bln. Bn., Camp Tyson, Tenn.
||Gardner, Jack Winston, Gulf Oil Corp., 1107 Union Natl. Bank Bldg., Wichita, Kans.
Gaul, George Howard, Sinclair-Prairie Oil Co., Box 807, Dickinson, N. D.
Gilbert, Thomas Harold, Valley Osage Oil Co., 623 Mayo Bldg., Tulsa, Okla.
Giles, Howard Windfield, Gulf Research & Dev. Co., Box 161, Flora, Ill.

||Green, Charles Frederic, 1958 Vallejo St., San Francisco, Calif.
Grow, George C., Jr., Peoples Nat. Gas Co., 545 William Penn Way, Pittsburgh, Pa.
Guffey, Vernon E., W. C. McBride, 625 Wright Bldg., Tulsa, Okla.
||Gulde, Andros, Pure Oil Co., 402 Second Natl. Bank Bldg., Saginaw, Mich.
||Gutschick, Raymond Charles, Geol. Dept., Univ. of Illinois, Urbana, Ill.
Ham, William Eugene, Oklahoma Geol. Survey, Norman, Okla.
Hancock, Willis Pritchard, Imperial Oil Ltd., 606 Second St., W., Calgary, Alta., Canada
||Harang, Jack Francis, Gulf Oil Corp., 1902 Gulf Bldg., Houston, Tex.
Harper, Paul A., Cities Service Oil Co., 1020 Central Bldg., Wichita, Kans.
Haseltine, William Lloyd, Magnolia Petr. Co., Box 239, Wichita Falls, Tex.
||Hawkins, Allen Gentry, Pure Oil Co., Box 271, Tulsa, Okla.
Hawkins, Harold H., National Park Service, Richmond, Va.
||Heald, Charles Leslie, 2202 N. Santa Anita Ave., Altadena, Calif.
Henning, John L., Majestic Hotel, Lake Charles, La.
||Hill, Robert Cowdery, Box 113, Ojai, Calif.
Hinchey, Norman Shreve, Shell Oil Co., Inc., Box 476, Centralia, Ill.
Hole, Herbert Wray, New Brunswick Gas & Oilfields, Ltd., Box 194, Moncton, N. B., Canada
||Holliday, Samuel, 2215 Bellaire Bldg., Houston, Tex.
||Hopf, Robert William, Shell Oil Co., Inc., 641 M. & M. Bldg., Houston, Tex.
||Hurd, Clinton O., Gen. Del., Chandler, Okla.
Imlay, Ralph Willard, U. S. Geol. Survey, 331 U. S. Natl. Museum, Washington, D. C.
||Jenkins, Philip, Kentucky-West Virginia Gas Co., Paintsville, Ky.
||Kemp, Edward Rogers, Sinclair Wyoming Oil Co., Box 808, Evansville, Ind.
||Knight, Wilbur Hall, 310 S. Tenth, Laramie, Wyo.
||Kummel, Bernhard, Jr., Science Hall, Univ. of Wisconsin, Madison, Wis.
||Latta, Lee Allen, 2414 N. Shartel, Oklahoma City, Okla.
Lewis, J. Volney, c/o H. B. McCoy, Bureau of Foreign & Domestic Commerce, Washington, D. C.
||Lewis, Wendell L., Houston Oil Co., Beeville, Tex.
Lilienborg, B. A., 1012 N. Rockford, Tulsa, Okla.
Loeblich, Alfred Richard, Jr., Geol. Dept., Tulane Univ., New Orleans, La.
Madera, Fred, The Ohio Oil Co., Box 1607, Hobbs, N. Mex.
Magalis, Cyrus West, Luling Oil & Gas Co., 2300 Alamo Natl. Bldg., San Antonio, Tex.
||Maravich, Milan D., Stanolind Oil & Gas Co., Box 1099, Shawnee, Okla.
Martin, V. Dale, Military Chemical Works, Inc., Columbus, Kans.
Martinez, Fidel Castilla, Cia Petrolera "My M," S. A., Apt. 347, Monterrey, N. L., Mexico
Mathias, Henry Edwin, Colorado College, Colorado Springs, Colo.
Matter, John Emerson, 712 E. Mendocino St., Altadena, Calif.
Mayer, Maurice Joseph, Jr., 1170 Park Blvd., Baton Rouge, La.
McAdams, Ronald Earl, Shell Oil Co., Inc., 200 Alamo Natl. Bldg., San Antonio, Tex.
||McClain, Forrest Milton, 1408 Fourth Ave., Columbus, Ga.
McClain, Orville Graves, Southern Minerals Corp., 411 N. Broadway, Corpus Christi, Tex.
McCormick, Robert Louis, Plymouth Oil Co., Box 564, Sinton, Tex.
||McCoy, James Roy, Phillips Petr. Co., Staley Bldg., Wichita Falls, Tex.
McMasters, John Herbert, Honolulu Oil Corp., 410 Professional Bldg., Bakersfield, Calif.
Meholin, Graydon L., Sinclair-Prairie Oil Co., Tyler, Tex.
||Meyer, Ruskin H., Republic Nat. Gas Co., 1505 Federal St., Dallas, Tex.
||Miley, Roy Allen, Texas Petr. Corp., Apt. 877, Bogota, Colombia, S. A.
Miller, Buford, Benedum & Trees, 2305 Esperson Bldg., Houston, Tex.
||Miller, Harry A., 311 E. Fourth St., Edmond, Okla.
||Miller, John R., U. S. Geol. Survey, Box 27, Limerick, Me.
||Ming, Raymond E., U. S. Naval Air Station, Quonset Point, R. I.
||Mitchell, Robert Oliphant, Stanolind Oil & Gas Co., 429 First Natl. Bank Bldg., Wichita, Kans.
Mix, Adrian Elroy, Socony-Vacuum Oil Co., Apt. 246, Caracas, Venezuela, S. A.
Moore, Gilbert Parvin, Auto Ordnance Corp., 517 Union Natl. Bldg., Wichita, Kans.
Moore, James A., Union Sulphur Co., Sulphur, La.
||Moore, Joe Hiram, Box 1457, Hobbs, N. Mex.
Morey, Philip S., Shell Oil Co., Inc., 2000 Alamo Natl. Bldg., San Antonio, Tex.
Nauss, Arthur William, Vermilion, Alta., Canada
||O'Brien, Joseph Alfred, Shell Oil Co., Inc., Box 1347, Shreveport, La.
Park, Lee Brown, Atlantic Refg. Co., Box 871, Midland, Tex.
||Patterson, Archibald Balfour, Phillips Petr. Co., Esperson Bldg., Houston, Tex.
||Pearson, Raymond Elliott, 3110 E. Sixth St., Long Beach, Calif.
Pierce, William Gamewell, U. S. Geol. Survey, Washington, D. C.
||Pullen, Milton William, Jr., 807 W. Washington St., Champaign, Ill.

||Quigley, Claude Merle, Jr., 1600 Louisiana, Houston, Tex.
Rabensburg, Aubrey Henry, Continental Oil Co., Box 3126, Houston, Tex.
||Raman, Norman Dean, 1417 S. Park, Springfield, Ill.
||Renfroe, Charles A., 2804 Twenty-third St., Lubbock, Tex.
||Richards, David Taylor, Shell Oil Co., Inc., Box 221, Throckmorton, Tex.
Richards, Henry Caselli, Univ. of Queensland, Brisbane, Queensland, Australia
||Rincones, Carlos Vogler, Mene Grande Oil Co., Apt. 45, Barcelona, Venezuela, S. A.
||Robins, Anne M., R. F. D. Box 18, Center Conway, N. H.
||Rodgers, John, U. S. Geol. Survey, Washington, D. C.
||Rodgers, John Albert, Fohs Oil Co., Bourg, La.
Rossebo, C. B., Box 1273, Alice, Tex.
||Saubert, Robert W., Seismograph Service Corp., Kennedy Bldg., Tulsa, Okla.
Schempf, Foster John, 428 Crestwood Dr., Fort Worth, Tex.
||Scott, Arvin Forrest, Forest Dev. Corp., 1229 Milam Bldg., San Antonio, Tex.
Scott, Harold William, 246 Natural History Bldg., Univ. of Illinois, Urbana, Ill.
||Selover, Joseph Britton, Fischer Oil Co., 317 Court Bldg., Evansville, Ind.
||Shelton, John Sewall, U. S. Geol. Survey, Washington, D. C.
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||Silva, Will, c/o T. F. Roche, Texas Petr. Co., Barranquilla, Colombia, S. A.
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Skeeters, Warren Ware, Colorado School of Mines, Golden, Colo.
Sloss, Laurence Louis, Montana School of Mines, Butte, Mont.
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Spaulding, Bernard B., The Texas Co., Box 476, Mattoon, Ill.
||Stainforth, Robert Masterman, Trinidad Leaseholds Ltd., Pointe-a-Pierre, Trinidad, B. W. I.
Stangl, Frank J., Jr., 2348 Albans, Houston, Tex.
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Tamborello, Anthony J., 12 Sidney St., Houston, Tex.
Tarver, Earl A., Superior Oil Corp., 418 Natl. Bank of Tulsa Bldg., Tulsa, Okla.
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||Tierney, James A., Hunt Oil Co., Palestine, Tex.
||Verckler, Stewart Peter, Box 532, Abilene, Kans.
Volk, Russell H., Plains Expl. Co., Denver, Colo.
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Wells, John Cawse, Standard Oil Co. of Calif., 225 Bush St., San Francisco, Calif.
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||Woodbury, Homer Olwin, U. S. Bur. of Mines, Boulder, Colo.
Worrell, Frank Hansen, The Ohio Oil Co., Cement, Okla.
Wright, William Josiah, Dept. of Lands & Mines, Fredericton, N.B., Canada.
Younkman, Harry D., Albany Hotel, Tulsa, Okla.
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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 26, NO. 9 (SEPTEMBER, 1942), PP. 1548-1551, 2 FIGS.

Memorial

JOHN FITTS
(1879–1942)

John Fitts died suddenly of heart disease early in the morning of June 30, 1942, at his home in Sulphur. His death followed a visit the evening before with Mrs. Fitts, who was critically ill in the hospital in Sulphur, and she survived him only eleven days.

Stall, Ada, 1932

JOHN FITTS

Mr. Fitts was born at Carollton, Georgia, October 28, 1879. With his parents, he moved to Perry, Oklahoma, in 1893, where he attended the public school until 1897. Then, they lived at Atoka until 1912, when they moved to Ada. He married Miss Coga Marie Bond, April 22, 1906, and they made their home in Ada until about two years ago, when he purchased a home at the west edge of Sulphur. He was elected to associate membership in our Association in 1927.

For a time Mr. Fitts worked as an electrical engineer, and he became so proficient that he installed electrical plants in several towns. While he never had an opportunity to get a college education, he had a remarkable amount of native ability, which included the power of close observation linked with a very exceptional memory for details. Though he lacked the regular university training in geology, he became an outstanding field geologist and a recognized authority on the distribution of the geological formations, especially in the Arbuckle and Ouachita mountains, and he did some consulting work in geology as far away as Kentucky.

During his residence at Ada, his interest in geology grew by leaps and bounds, until it became the controlling passion of his life. He lost no opportunity to accompany any geologist who came into the region for field studies, and thus became the close friend of the leading geologists of the United States Geological Survey and the Oklahoma Geological Survey and oil-company geologists. Also, he was untiring in his individual field studies, and as a result he not only knew the distribution of practically every geological formation exposed in the region, but learned and remembered the names of nearly all the characteristic fossils of each formation, both megascopic and microscopic. Also, he studied the plants and was familiar with those which commonly grow on various types of soil.

As a result of his mastery of the geology, he became an ideal leader of geologists and students on field trips in various parts of the region, and he found his greatest delight in such trips.

In addition to his knowledge of the characteristics and distribution of the geological formations on the surface, he was a skilled subsurface geologist. In the study of well cuttings he could readily recognize the formation which the drill was penetrating. Then he would remember the details of all of these changes for every well. Also, he had a phenomenal memory for descriptions of locations, and generally without hesitation, he would name the section, township and range for practically any locality.

In petroleum geology he did leasing for a number of large companies and helped in the development of their properties. He did some personal prospecting for oil, but his individual efforts did not prove very successful. Many men were made very wealthy by applying the information secured from his studies, while he profited little. During the most active part of his career, he exhibited an amazing power of endurance, driving long distances night and day, through cold, storm, and mud, and with little sleep or rest.

John was generous to a fault. He would take his own car at any time to take anyone to some special location in the mountains. He was a patron of the Boy Scouts, and helped establish a camp for them on his farm near Bromide. He gave money freely to those in need. A friend told me that when they were driving through Bromide, John went to the home of a woman who was very ill and ordered that arrangements be made to take her to a hospital. His explanation for the expenditure was, "The little kids will need her."

He helped to plan the first trips to the Ada region for the writer's class in paleontology. He with other citizens of Ada met us at the train and furnished cars to take us to a number of good fossil localities. On these trips, he soon learned the names of the students and frequently he re-named some of them. An attractive girl, Maurine, he at once dubbed "Murine, good for the eyes." He visited with individual students, and soon differentiated between the alert and interested, and the laggards.

He arranged for the placing of the large Devonian fossil tree on the edge of the campus at Ada, as a memorial to David White, the noted paleobotanist and geologist. He had much to do in helping Ada get her excellent water supply from the big spring in the mountains. In fact, Ada and many of its business men owe much to him for better business conditions due to his activity in helping to develop the oil and gas fields of that region. So it is very appropriate that the largest field and adjacent town bear his name.

While a great friend of many people, he had marked individual characteristics, so

much so, that some one said that as there was just one Lincoln, so there was just one John Fitts, and the latter had many of the homely, sterling characteristics of the Great Emancipator.

CHARLES E. DECKER

UNIVERSITY OF OKLAHOMA, NORMAN, OKLAHOMA
July, 1942

HUGH MOORE ELEY
(1902–1942)

On the ninth day of May, 1936, Hugh Moore Eley received the Sigma Gamma Epsilon award as the ranking graduate in geology in his class at the University of Oklahoma. This high honor was the culmination of higher education which had begun fourteen years previously. Six years and one day later he died.

HUGH MOORE ELEY

Hugh Moore Eley was born at Corsicana, Texas, on December 1, 1902. His early life was spent on a farm near the town of Elmer, Jackson County, Oklahoma, and he was educated in the Oklahoma public schools.

His first period of higher education was spent at the University of Oklahoma from 1922 to 1927, at which time he received the A.B. degree. While attending the University he met Thelma Gore whom he married in 1925. Following his graduation he took up public school teaching and administrative work. He handled this profession most successfully, and as a young man was superintendent of one of the largest consolidated school districts in the state of Oklahoma. While engaged in teaching, he studied meteorology and geology during summer sessions at the University of Colorado. In 1935, he gave up a promising

future as a public school man to resume the study of geology, the science which had always held his chief interest.

Hugh spent the summer months of 1936 as junior geologist in the proposed Big Bend National Park area. He assisted Dr. Ross Maxwell in preparing the first geologic map of the proposed park area. His work of that summer was the basis of subsequent graduate study at the University of Oklahoma for the following two years, and he received the degree of Master of Science in 1939. During the year 1938–1939, he held the rank of instructor in geology and carried a full teaching load while finishing his graduate work. His academic work met the high standards of the Sigma Xi Research Society and he was elected to that organization in 1937.

His master's thesis, "Geology of the Proposed Big Bend National Park Area," is an excellent reconnaissance report on the geology of that region. His large collection of fossils from the Gulf series equivalents in the Big Bend country was the basis of excellent detailed correlations between the Atlantic Coastal Plain, the Gulf Coastal Plain, and the isolated area of his work.

In June, 1939, he joined the geological staff of the Magnolia Petroleum Company. His first assignment was in Ohio, and after a year he was transferred to Midland, Texas. From June, 1940, until a few weeks before his death he was doing subsurface geology in West Texas. In that area he was most successful in the practical, systematic application of his knowledge of early and middle Paleozoic micropaleontology. In true scientific spirit, he was always ready to counsel his contemporaries in their perplexing problems of stratigraphic determinations at drilling wells, as critical depths were reached.

Eley was an avid sports enthusiast and had been a successful basketball coach during the period of his public school career. He took particular delight in the fact that college athletes sought his courses. Not that he "pulled his punches," but he had a tolerance and understanding of his pupils which inspired them to measure up to the high standard he required. His true teaching spirit is attested by the regular night-time tutoring sessions he held in addition to teaching a full schedule and keeping up with his graduate courses.

Along with his native ability and his limitless capacity for applied hard work, Eley's proclivity for making friends was a strong factor in achieving the enviable reputation he enjoyed. He revelled in congenial companionship. With his affable nature he made himself a congenial companion to all those with whom he had contact—whether other students, his pupils, fellow-teachers, fellow-geologists, or native ranchers in the Big Bend country. Hugh Eley will live as a solid American in the minds of those who knew him as teacher, scientist, and friend.

William J. Hilseweck

Fort Worth, Texas
August 6, 1942

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 26, NO. 9 (SEPTEMBER, 1942), PP. 1552-1556

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The annual fall meeting of the Pacific Section of the Association, usually held in November, has been cancelled, according to E. J. BARTOSH, president of the Section. Regular monthly meetings at Los Angeles will continue and will be announced by special notice to members.

EDWARD J. FOLEY, recently with the Standard Oil Company of Egypt at Cairo, may be addressed at 931 Placer Street, Butte, Montana.

L. G. HUNTLEY is on leave of absence from the Standard Oil Company of Venezuela. He may be addressed in care of J. B. Henry, Jr., 5500 Charles Street, Bethesda, Maryland.

DWIGHT C. ROBERTS, of the Sperry-Sun Well Surveying Company, Houston, Texas, has been promoted from regional to assistant general manager.

ALDEN W. FOSTER has closed his office as consulting engineer in Pittsburgh, having been appointed a captain in the Ferry Command of the Army Air Force.

E. B. BALDWIN, consulting geologist at Houston, Texas, is now a lieutenant in the navy, on active duty.

E. A. FREDERICKSON, assistant professor of geology at the University of Oklahoma, Norman, is a second lieutenant in the Army Air Force.

RALPH N. THOMAS, geologist with the Inland Gas Corporation, Ashland, Kentucky, is a first lieutenant in the Office of the Quartermaster General, Washington, D. C.

RONALD K. DEFORD, of the Argo Oil Company, Midland, Texas, has been teaching a "refresher course" in trigonometry offered to geologists and others who are preparing for work in the armed forces. Forty-four men were enrolled. There was no charge to paid-up members of the West Texas Geological Society.

JOHN W. REISS, formerly with the geological department of the Stanolind Oil and Gas Company, Houston, Texas, is a second lieutenant at the Army Advanced Pursuit School, Foster Field, Texas.

Lieutenant FORREST M. MCCLAIN may be addressed at 1408 Fourth Avenue, Columbus, Georgia.

GLENN G. BARTLE, dean at the University of Kansas City, Missouri, has been commissioned a lieutenant in the navy and assigned to an antiaircraft training and testing field.

J. H. PAGE, natural-gas engineer for the Kansas Corporation Commission for several years past, has been appointed superintendent of the Eastern Kansas Gas Company, Iola, Kansas.

JOHN ROBERT GISBURNE, recently in the Wichita, Kansas, office of the Shell Oil Company, Inc., is an ensign at the Boston Navy Yard.

GEORGE E. DUNLAP, of the Sun Oil Company, Dallas, Texas, has been commissioned an ensign in the navy.

LLOYD E. MILLER, Sun Oil Company, Dallas, is an ensign in the navy. He reported at Newport, Rhode Island, September 9.

O. F. VAN BEVEREN, recently with the California Arabian Standard Oil Company, Bahrein Island, Persian Gulf, is at 4361 Colfax Avenue, North Hollywood, California.

LOUIS KEHRER, recently with the United British Oilfields of Trinidad, Ltd., is now with the Shell Company of Ecuador, at Quito, Ecuador.

CARROLL H. WEGEMANN, who has been at Omaha, Nebraska, for several years with the National Park Service, may be addressed at 643 McCormick Street, Shreveport, Louisiana.

CLELAND N. CONWELL of Idaho Springs, Colorado, is engineer in the petroleum department of Stearns-Rogers Manufacturing Company at Corpus Christi, Texas.

WILLIAM DICK MOTT, formerly with the Island Exploration Company, Port Moresby, Papua, is in the Royal Australian Air Force. He may be addressed in care of R. J. Mott, Ashton Prairie, North Queensland.

JOHN W. RUWWE, who has been a petroleum geologist with the Phillips Petroleum Company at Shawnee and Bartlesville, Oklahoma, for the past 6 years, has been called to active duty as an ensign in the navy. His permanent address is 3641 Bates Street, St. Louis, Missouri.

A pamphlet, *Some Military Applications of Elementary Mathematics*, can be obtained at 15 cents per copy by sending to the Institute of Military Studies, University of Chicago, Chicago, Illinois.

JOE A. CHAMPION, of the Standard Oil Company of Venezuela, at Caracas, may now be addressed at 111 East Elizabeth Street, Brownsville, Texas.

HENRY CARTER REA is with the British American Oil Company, at Calgary, Alberta.

JAMES L. CHASE, recently with the Olympic Refining Company, Long Beach, California, is working temporarily as a navy inspector.

WILLIAM T. SCHNEIDER, formerly district geologist and engineer for the Honolulu Oil Corporation in Midland, Texas, is now a 1st lieutenant in the Corps of Engineers, Company A, 30th E. T. Battalion, Fort Leonard Wood, Missouri.

FREEMAN L. ORMAN, JR., who was with the Republic Natural Gas Company in Dallas, Texas, may now be addressed at Box 374, Austin, Texas. He is an apprentice seaman, U.S.N.R., Notre Dame University, Notre Dame, Indiana.

FRANK F. HORNKOHL of the Hornkohl Laboratories, Bakersfield, California, is a captain in the Air Corps at Wright Field, Dayton, Ohio.

CARL L. BRYAN is a lieutenant in the U. S. Navy and may be addressed at 2405 Isabella Avenue, Houston, Texas. He was formerly with the Gulf Research and Development Company at Pittsburgh, Pennsylvania.

CLYDE B. ADAMS has changed his address from the Socony-Vacuum Oil Company New York, to 93 Paul Revere Road, Needham Heights, Massachusetts, as he is now in the U. S. armed forces.

BENNETT FRANK BUIE, of the Standard Oil Company of Texas, who has been at Laredo since his return from India in 1941, has been transferred to Midland, Texas.

G. R. CARTER, of the Gulf Oil Corporation, Midland, Texas, has been in the photographic school at Lowry Field, Denver, Colorado.

RUSSELL R. SIMONSON, recently with the Union Oil Company of California, is petroleum engineer and geologist with the North American Oil Consolidated, Taft, California.

ROBERT DYK is a party chief with the Western Geophysical Company, Bakersfield, California.

R. E. MCADAMS, of San Antonio, Texas, is a lieutenant in the 362d Infantry, Camp White, Oregon.

FRANCIS N. BOSCO is a consulting geologist and petroleum engineer at 2166 South Washington, Denver, Colorado.

FRANK J. GARDNER, formerly with the *Rinehart Oil News* is a lieutenant in the 582d Ordnance Co. (Am.), 2d Army Depot, Nashville, Tennessee.

NATIONAL SERVICE COMMITTEE PROGRESS REPORT[1]

F. L. AURIN[2]
Fort Worth, Texas

To members of the American Association of Petroleum Geologists:

The following is a brief summary of the latest developments of the work of the National Service Committee. Our committee is greatly indebted to K. C. Heald for the energetic and effective work he has accomplished in contacting the different branches of the Armed Forces and in calling to their attention the training and experience of geologists for utilization in the War Effort. Our efforts to include the geologist, as a geologist, in the Armed Forces is continuing and very encouraging progress has been made. It is our hope that this program will become effective at an early date and that we can soon make this announcement to you.

The Army Specialist Corps is still very anxious to receive applications for Radar Work, and anyone who can qualify should write directly to W. O. Hotchkiss, Deputy Director General of the Army Specialist Corps, Washington, D. C.

We are happy to report that many of our members and non-members have entered the Air Corps as Interpreters of Aerial Photographs. Photo Intelligence and Foreign Intelligence officers and many more geologists can be used in that branch of service, and it is suggested that anyone interested and qualified should communicate with Major Chas. G. Morgan, Room G-742, Annex No. 1, Gravelly Point, Washington, D. C. Major Morgan is a geologist and has the vision to realize that geologists are well trained and have the proper experience to be Interpreters of Aerial Photographs and Intelligence Officers. In the event that you have made application for this type of work through the Civilian Aid Committees, or the Appointment and Procurement Section of the Air Corps, and have not received notice of appointment, please communicate with Major Morgan.

The qualifications for Soil Stabilization work in the Corps of Engineers have been changed since the first announcement. Present qualifications are that the applicant should have at least two years of highway-construction experience, and that he is now, or has been, a commissioned officer in the Army or Navy. The present requirements of the Armored Force in "Terrain Studies" have been filled.

The National Service Committee has also been very active in cooperating with many branches of the Armed Forces and governmental agencies other than those mentioned, for the possible efficient use of geologists in their programs. Any changes in the situation will be announced to you from time to time in the monthly *Bulletin*.

[1] Manuscript received, September 8, 1942.

[2] Temporary chairman, A.A.P.G. national service committee.

BINOCULARS FOR THE NAVY

A pressing need for binoculars of the proper type has again been announced by the Public Relations Office Eighth Naval District, United States Navy, in an appeal to owners of these important instruments who have not yet turned them over to the Navy for the duration of the war. The call for these glasses is made because there are many uses that the Navy can make of binoculars on the high seas and the supply is not yet adequate to fill the need. The binoculars desired are Zeiss, or Bausch & Lomb, in sizes 6×30 or 7×50. These are the types and sizes specified and anyone having a pair is urged to make them available to the Navy. If glasses are the type needed they may be shipped to the Naval Observatory, Washington, D. C., or if information is desired the Public Relations Office of the Navy in New Orleans may be contacted. Caution is urged in packing them so they will not be damaged in transit and a card bearing the owner's name and address should be enclosed. The Navy will pay $1.00 for the use of the binoculars and if they are still in use at the end of the war they will be returned to their owner.

SELECTIVE SERVICE SYSTEM BULLETIN

NATIONAL HEADQUARTERS—SELECTIVE SERVICE SYSTEM

21st Street and C Street, N.W., Washington, D.C.
Official Release, August 5, 1942

OCCUPATIONAL BULLETIN NO. 15 EFFECTIVE: AUGUST 5, 1942

SUBJECT: PETROLEUM, NATURAL GAS AND NATURAL GASOLINE ACTIVITY

1. The War Manpower Commission has approved certain occupations in petroleum, natural gas and natural gasoline activities as essential to the support of the war effort.

2. This bulletin covers the following essential activities as listed in the amendment to Local Board Release No. 115:

(a) Production of petroleum, natural gas and petroleum and coal products: Drilling, rig building and maintenance service operations; petroleum refining. Includes also production of tar and pitch; coal gas, coke.

3. The attached sheets list occupations in petroleum, natural gas and natural gasoline activities that require a reasonable degree of training, qualification or skill. The purpose of the list is to state the important occupations in these activities that must be filled by persons capable of performing the duties involved so that the activity may maintain efficient production. The list is restricted to occupations requiring six months or more of training and preparation.

4. In classifying a registrant employed in these activities, consideration should be given to the following:

(a) The training, qualification or skill required for the proper performance of the duties involved.

(b) The registrant's training qualification or skill for engaging in the occupation.

(c) The availability of persons to replace the registrant who have similar training, qualification or skill, or who can be trained to have it; and the time in which such replacement can be made.

LEWIS B. HERSHEY, Director

CRITICAL OCCUPATIONS
PETROLEUM, NATURAL GAS AND NATURAL GASOLINE ACTIVITY

Accountant
Acid Recovery Plant Operator
Analyst, Geophysical
Blacksmith
Boilermaker
Brickmason, Refractory
Carbon Black Plant Operator
Carpenter
Cementing (Well) Operator
Chemist
Chief Clerk
Claim Adjuster
Coke Burner
Coke-Oven Mason
Coke-Oven Repairman
Compounder
Computer, Geophysical
Core Analysis Operator
Dehydration Plant Operator
Derrickman
Designer, Equipment
Dispatcher
Draftsman
Driller
Electrical Logging Operator
Electrician
Engineer Operating, Chief Station
Engineer Operating, Chief Station, Boilerhouse
Engineer Operating, Compressor
Engineer Operating, Hoist
Engineer Operating, Locomotive
Engineer Operating, Natural Gas
Engineer Operating, Power
Engineer Operating, Processing
Engineer Operating, Supervising
Engineer Operator, Processing
Engineer, Professional & Technical
Ethyl Blender
Filter House Operator
Fishing Tool Operator
Foreman, Boilermaker
Foreman, Carpenter
Foreman, Coal Washing
Foreman, Coke Products
Foreman, Communications
Foreman, Electrician
Foreman, Filler & Package
Foreman, Fire Crew
Foreman, Coal Products
Foreman, Gas Measurement
Foreman, Heat Treating
Foreman, Insulator
Foreman, Leads
Foreman, Machine Shop
Foreman, Maintenance & Repair
Foreman, Petroleum Refining
Foreman, Pipe Shop
Foreman, Production
Foreman, Rigbuilding
Foreman, Shipping
Foreman, Tank Cleaning
Gas-Lift Plant Operator
Gasoline Plant Operator
Generator Operator
Geologist
Geophysicist
Glass Blower (Instrument)
Grease Maker
Gun-Perforating Operator
Houseman
Inspector, Mechanical
Instrument Repairman
Insulator, Boiler, Steam, Etc.
Interpreter, Geophysical
Laboratory Technician (Semi-Prof.)
Landman, Chief or Division
Lead Burner
Machinist
Maintenance Mechanic
Manager, Employment
Manager, Office
Manager, Operations
Manager, Personnel
Manager, Traffic
Material and Warehouse Inspector
Material Inpector
Metal and Equipment Inspector

Geologists who have made application to the Air Corps, to the Civilian Aid Committees and Appointment Section, and have not received notice of appointment should notify Major CHARLES G. MORGAN, Room G-742, Annex No. 1, Gravelly Point, Washington, D. C., so that he may get the files on these applications from that Section and process them.

R. DANA RUSSELL, of the Louisiana State University, School of Geology, Baton Rouge, has gone to the University of California, Division of National Defense Research, U. S. Navy Radio and Sound Laboratory, San Diego, California.

H. WESTON ROBBINS is with the Soil Conservation Service, in field work on a groundwater map of Wyoming.

E. O. BUCK, recently assistant director, is now district director of production, District No. 3, Office of Petroleum Coordinator for War. His address is 245 Esperson Building, Houston, Texas.

HENRY F. SCHWEER, geologist of Oklahoma City, is a captain in the technical division of the Army Air Corps.

ROBERT L. CLARKE, of the Union Oil Company of California, Midland, Texas, has been commissioned a lieutenant in the navy, reporting to the Naval Training School at Harvard University, September 1.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

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Carter Oil Company, Mt. Pleasant

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Business Manager - - - - Gordon H. Pringle
Ohio Oil Company, Mt. Pleasant

Meetings: Second Wednesday of month at 6:30 P.M., from November to April. Informal dinner followed by discussions. Meetings held in rotation, at Lansing, Mt. Pleasant, Ann Arbor, Grand Rapids. Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - Tom McGlothlin
Gulf Refining Company, Box 1105

Vice-President - - - - - - David C. Harrell
Carter Oil Company, Box 1490

Secretary-Treasurer - - - - - A. A. Holston
Stanolind Oil and Gas Company, Box 689

Meetings: First and third Wednesdays of each month from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - Paul L. Bartram
Phillips Petroleum Company

Vice-President - - - George C. Hollingsworth
Independent Producer

Secretary-Treasurer - - - - - Frank Neighbor
Sinclair Prairie Oil Company

Asst. Secretary-Treasurer - - - C. E. Hannum
The Texas Company

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - Richard W. Camp
Consolidated Gas Utilities Corporation
Braniff Building, Box 1439

Vice-President - - - - - - Dean A. McGee
Kerlyn Oil Company, 2009 First Natl. Bldg.

Secretary-Treasurer - - - - - - H. T. Brown
Cities Service Oil Company, Box 4577

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every Thursday at 12:00 Noon, Skirvin Hotel Coffee Shop.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - Robert L. Cassingham
Amerada Petroleum Corporation

Vice-President - - - - - - - U. R. Laves
Consulting Geologist, 723 S. Broadway, Ada, Okla.

Secretary-Treasurer - - - - - Martyna Garrison
Amerada Petroleum Corporation

Meets the fourth Monday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

THE STRATIGRAPHIC SOCIETY OF TULSA
TULSA, OKLAHOMA

President - - - - - - - - Ralph A. Brant
Atlantic Refining Company, Beacon Building

Vice-President - - - - - Kilburn E. Adams
The Texas Company

Secretary-Treasurer - - - - Charles W. Lane
The Pure Oil Company, Box 271

Meetings: Second and fourth Wednesdays, each month, from October to May, inclusive, at 8:00 P.M.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - Glenn Scott Dillé
Consulting Geologist, Atlas Life Building

1st Vice-President - - - - - Maurice R. Teis
The Ohio Oil Company

2nd Vice-President - - - - Myron C. Kiess
The Pure Oil Company

Secretary-Treasurer - - - Louis H. Desjardins
Aero-Geologist, 739 Kennedy Bldg.

Editor - - - - - - - - Constance Leatherock
Tide Water Associated Oil Company

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Thursday (October-May), Michaelis Cafeteria, 507 South Boulder Avenue.

TEXAS

DALLAS PETROLEUM GEOLOGISTS
DALLAS, TEXAS

President - - - - - - - - - - J. A. Lewis
Core Laboratories, Inc., Santa Fe Building

Vice-President - - - - - - - C. C. Albritton
Southern Methodist University

Secretary-Treasurer - - - - - - Barney Fisher
Coronado Corporation

Executive Committee - - - - Fred A. Joekel
Magnolia Petroleum Company, Box 900

Meetings: Regular luncheons, first Monday of each month, 12:15 noon, Petroleum Club, Adolphus Hotel. Special night meetings by announcement.

TEXAS

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - - C. I. Alexander
Magnolia Petroleum Company, Box 780

Vice-President - - - - - - - - E. B. Wilson
Sun Oil Company, Box 807

Secretary-Treasurer - - - - Laurence Brundall
Shell Oil Company, Inc., Box 2037

Meetings: Monthly and by call.
Luncheons: Every Monday at 12:00 noon, Blackstone Hotel.

FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

President - - - - - - - - - - J. B. Lovejoy
Gulf Oil Corporation

Vice-President - - - - - - - Karl A. Mygdal
The Pure Oil Company

Secretary-Treasurer - - - Richard H. Schweers
The Texas Company

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

President - - - - - - Carleton D. Speed, Jr.
Consulting Geologist, Second National Bank Bldg.

Vice-President - - - - - - Donald M. Davis
Pure Oil Company

Secretary - - - - - - - Wayne Z. Burkhead
Union Oil Company of California
1134 Commercial Building

Treasurer - - - - - - James W. Kisling, Jr.
Amerada Petroleum Corporation, Esperson Bldg.

Regular meeting held every Thursday at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

President - - - - - - - - - - Robert Roth
Humble Oil and Refining Company

Vice-President - - - - - - - - - F. E. Melott
Deep Rock Oil Company

Secretary-Treasurer - - - - - Dolphe E. Simic
Cities Service Oil Company

Luncheons and evening programs will be announced.

SOUTH TEXAS GEOLOGICAL SOCIETY
SAN ANTONIO AND CORPUS CHRISTI TEXAS

President - - - - - - - W. W. Hammond
Magnolia Petroleum Company, 1709 Alamo National Building, San Antonio

Vice-President - - - - - - - J. M. Hancock
Southern Minerals Corporation, Corpus Christi

Secretary-Treasurer - - - - - Wm. H. Curry
Wellington Oil Company, 1108 South Texas Bank Building, San Antonio

Meetings: Third Friday of each month alternately in San Antonio and Corpus Christi. Luncheon every Monday noon at Milam Cafeteria, San Antonio, and at Plaza Hotel, Corpus Christi.

WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - - Ronald K. DeFord
Argo Oil Corporation

Vice-President . . . . . . Bernerd A. Ray
Tide Water Associated Oil Company

Secretary-Treasurer - - - William M. Osborn
Consulting Geologist, Box 707

Meetings will be announced

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P. O. Box 2385

President - - - - - - - - Charles Brewer, Jr.
Godfrey L. Cabot, Inc., Box 1473

Vice-President - - - - - - - - H. J. Wagner
Public Service Commission

Secretary-Treasurer - - - - - - R. S. Hyde
West Virginia Gas Corporation
Box 404, Charleston, W.Va.

Editor - - - - - - - - Robert C. Lafferty
Owens, Libbey-Owens Gas Department
4007 Staunton Ave., Charleston, W.Va.

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - - - Frank Goldstone
Shell Oil Company, Inc., Houston, Texas

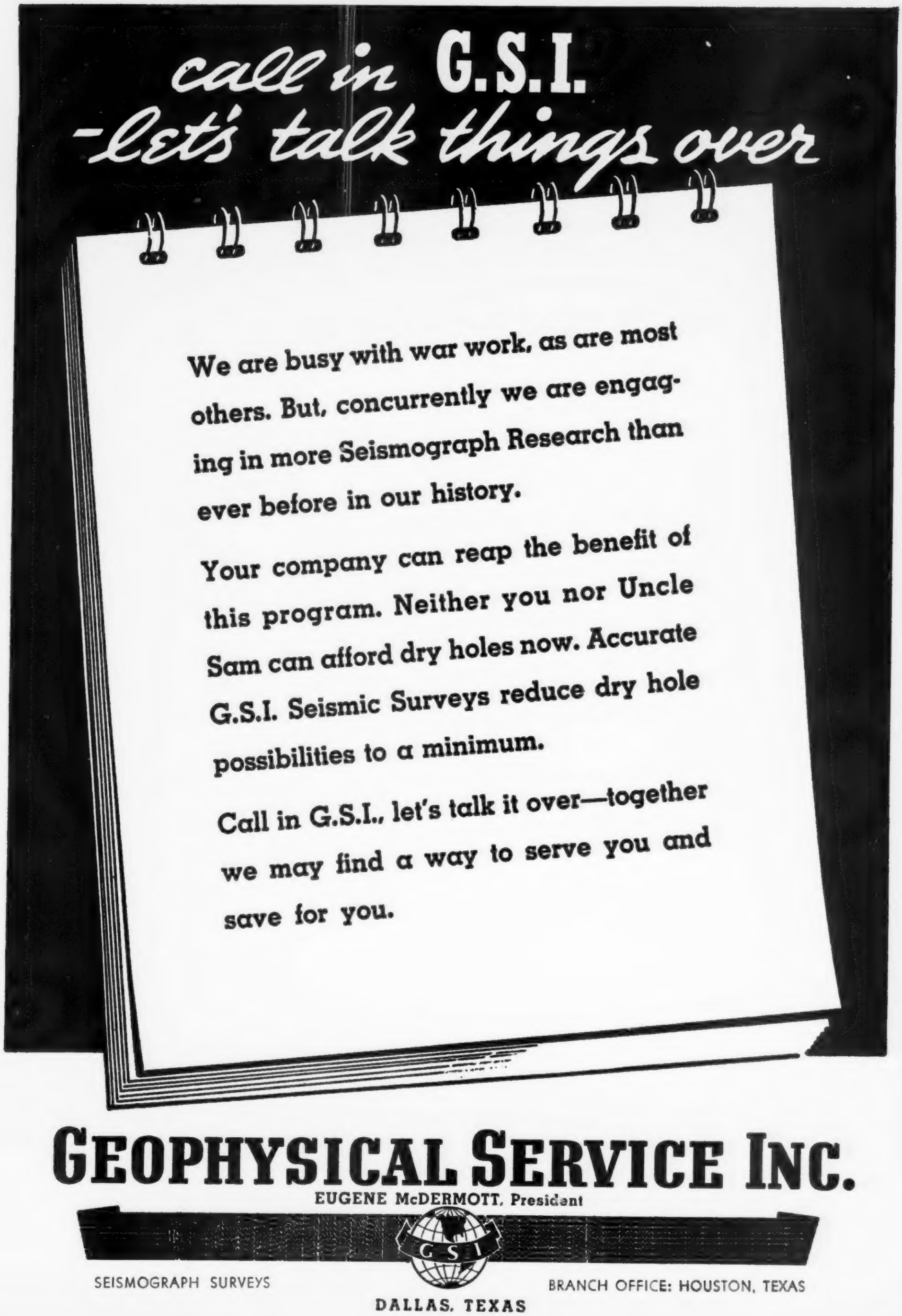
Vice-President - - - - - - - - R. D. Wyckoff
Gulf Research and Development Company
Pittsburgh, Pennsylvania

Editor - - - - - - - - - - - J. A. Sharpe
Stanolind Oil and Gas Company, Tulsa, Oklahoma

Secretary-Treasurer - - - - - - - T. I. Harkins
Independent Exploration Company, Houston, Texas

Past-President - - - - - - - - H. B. Peacock
Geophysical Service, Inc., Houston, Texas

Business Manager - - - - - - - - J. F. Gallie
P.O. Box 2585, Houston, Texas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